DO EXOPLANETS SHRINK WITH AGE?

3 FREE eBOOKS

All About Space

ALL-NEW AR EXPERIENCE INSIDE

FÉLICETTE THE ASTROCAT

ANTIMATTER GALAXIES

HAS THE IMPOSSIBLE EXISTENCE OF THESE BEHEMOTHS JUST BECOME POSSIBLE?

+

ASTRONOMY VERSUS SATELLITES

ORBITAL SERVICE STATION

YOUR NIGHT SKY GUIDE

UNIVERSE'S WOBBLING PARTICLE

EVERYTHING YOU NEED TO KNOW ABOUT... THE SOLAR SYSTEM

FUTURE
ISSUE 119

CELESTRON

YOUR PERSONAL **TOUR GUIDE** TO THE **GALAXY**

IMAGINE discovering stars, planets and deep sky objects in real-time whilst also being able to accurately identify what you can see.
AWARD WINNING StarSense sky technology enables you to use your smartphone with this telescope, to do just that.
VIEW incredible detail through the 102mm objective lens with our special high transmission XLT optical light coatings.
PERFECT for observing brighter objects in the City and even more from Dark Sky Sites.

StarSense Explorer™ DX

Model shown StarSense Explorer DX 102AZ RRP £379.99 (phone not included)
Other models available: StarSense Explorer DX 130AZ, DX 6" SCT, DX5" SCT, LT 70AZ, LT 80AZ, LT 114AZ and LT 127AZ

For more information visit celestron.com/ssetelescopes Contact Celestron at enquiries@celestron.com

WELCOME

Issue 119

5 ISSUE HIGHLIGHTS

Satellites vs astronomy

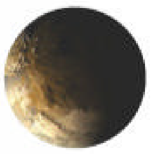
Meredith Rawls reveals the impact of artificial satellites on the night sky 28

The Solar System

Everything you need to know about our solar neighbourhood 30

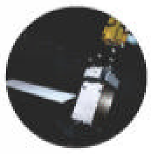
Félicette's journey into space

What happened when a cat blasted off into space 38



Do exoplanets shrink with age?

We may be closer to knowing why super-Earths are so scarce 68



Ask Space

Your questions answered by our team of experts 74

What if there was an equal but opposite to everything in the universe? That's one thing that scientists are faced with, as we discover this issue: could there be galaxies peppered throughout space and time that are equal and opposite to each other, creating a symmetry throughout the cosmos?

Let me introduce you to antimatter galaxies. Not long after the Big Bang, there were roughly equal amounts of matter and antimatter, with a bit more of an excess of the former. When the two crashed together, they annihilated, or 'cancelled', each other out. In our cover feature, we take a look at whether galaxies can be made up of antimatter – and the plans to find them. Turn to page 16 for the details.

Elsewhere in the issue, we take a look at the story behind the first – and only – cat that was blasted into space. Félicette was hailed as an international heroine after she returned from Earth orbit in October 1963. The cat was in good health on her return, but did we learn anything from her voyage to the stars? Space writer Stuart Atkinson reveals the details on page 38.

Also this month, we uncover whether exoplanets shrink with age, everything you need to know about our Solar System and much more. Enjoy the issue, I'll see you next time!

GEMMA LAVENDER

EDITOR-IN-CHIEF

36 SUBSCRIBE TO ALL ABOUT SPACE TODAY AND YOU'LL RECEIVE

- ✔ Great savings off the cover price
- ✔ Every issue delivered straight to your door or digital device before it arrives in the shops
- ✔ Exclusive subscriber edition covers

KEEP IN TOUCH /AllAboutSpaceMagazine @spaceanswers space@spaceanswers.com

INSIDE

16

ANTIMATTER GALAXIES

Has the impossible existence of these objects just become possible?

95 **CLAIM YOUR FREE EBOOKS**

Astronomy for Beginners, Book of the Moon & Book of Mars

> "THESE ANTIMATTER GALAXIES WOULD LOOK AND BEHAVE JUST LIKE ORDINARY GALAXIES" DAN HOOPER

LAUNCHPAD

06 News from around the universe
Earth has a lopsided core and Juno snaps Ganymede up close

FUTURE TECH

24 Orbital service station
If rockets could be refuelled in space, it could open up interplanetary travel

INTERVIEW

26 Dr Meredith Rawls
Rawls speaks to **All About Space** about the impact of low-Earth orbit satellites on ground-based astronomy

30 The Solar System
Join us on a tour through our current understanding of the planetary system we call home

38 Félicette: space cat
What happened when a feline was blasted off into space?

FOCUS ON

42 Weird nearby gamma-ray burst defies expectations

44 Food in space
Planning out martian menus means improving space cuisine

PLANET PROFILE

50 Mars
The Red Planet has a host of new robots investigating it

54 Muons
Revolutionary experiments may point to a new force, or an undiscovered subatomic particle

FOCUS ON

60 Europa may have deep-sea volcanoes

FOCUS ON

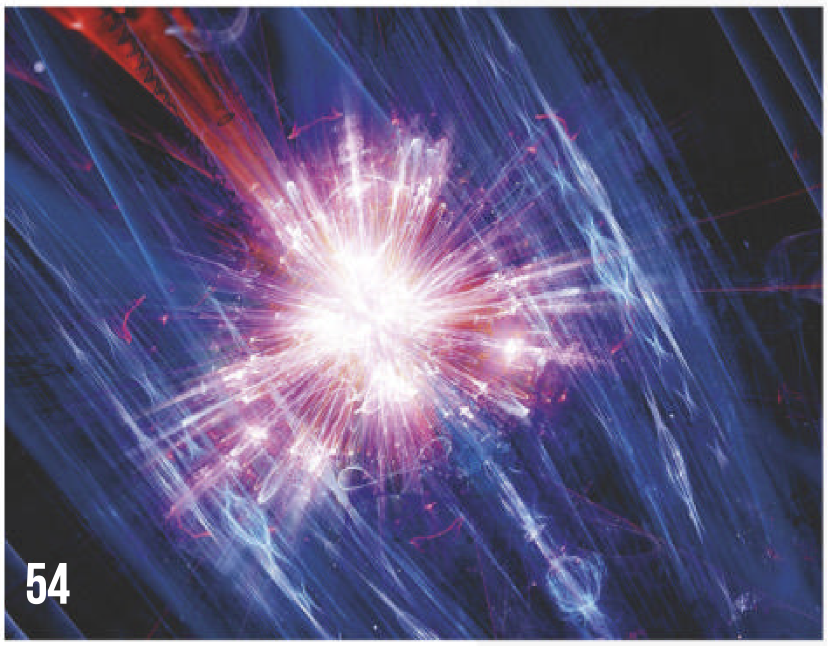
62 More accurate clocks may add more disorder to the universe

STAR PROFILE

64 Mira
This variable star is the queen of hide and seek

68 Are exoplanets shrinking with age?
Astronomers may be closer than ever to knowing why super-Earth exoplanets are so scarce

74 Ask Space
Your questions answered by our panel of experts



STARGAZER

78 What's in the sky?
82 Month's planets
84 Moon tour
85 Naked eye & binocular targets
86 Deep sky challenge
88 The Northern Hemisphere
90 Astroshots
92 Telescope review
96 In the shops

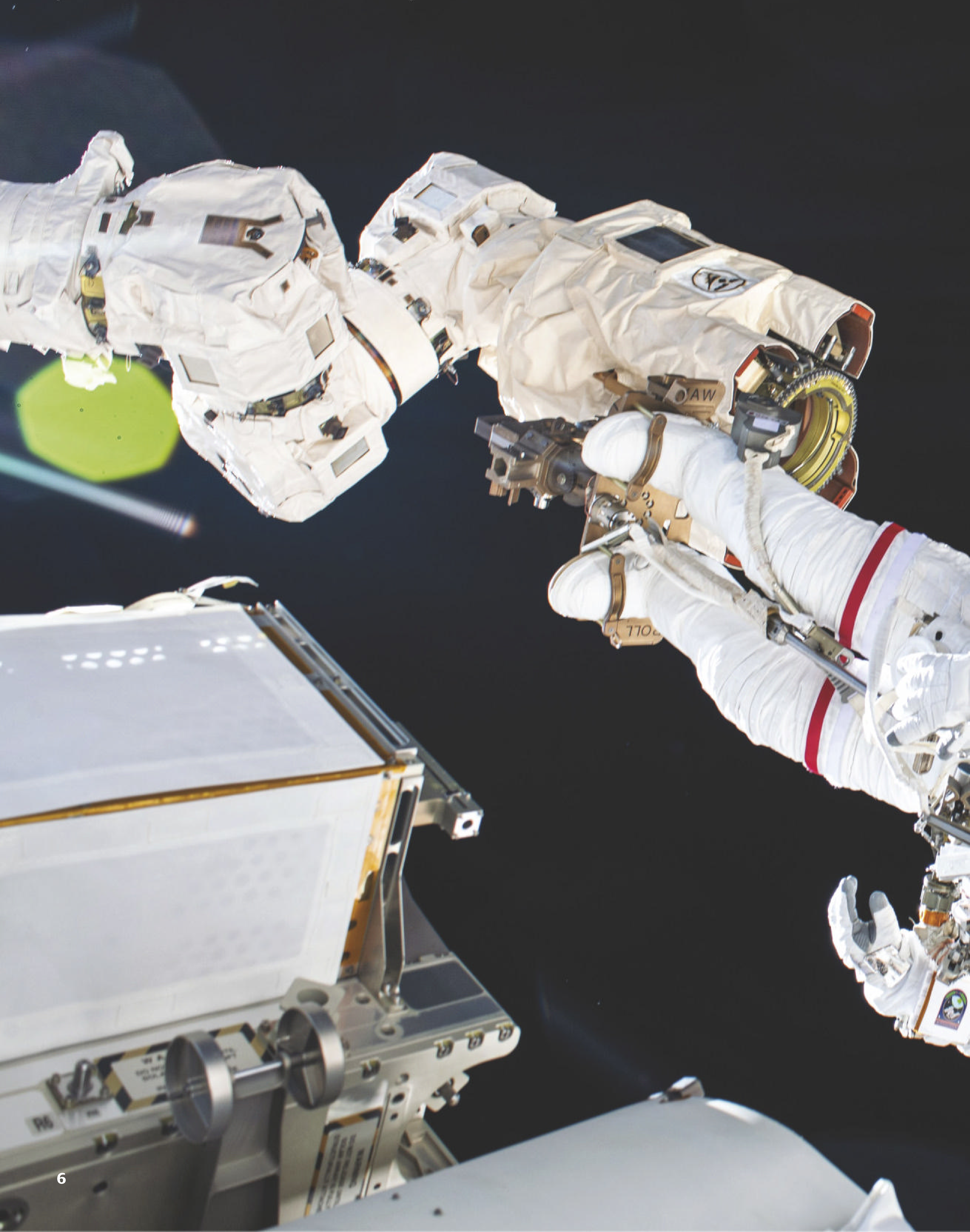
WIN!
MEADE POLARIS 130 MD
WORTH £250!
15

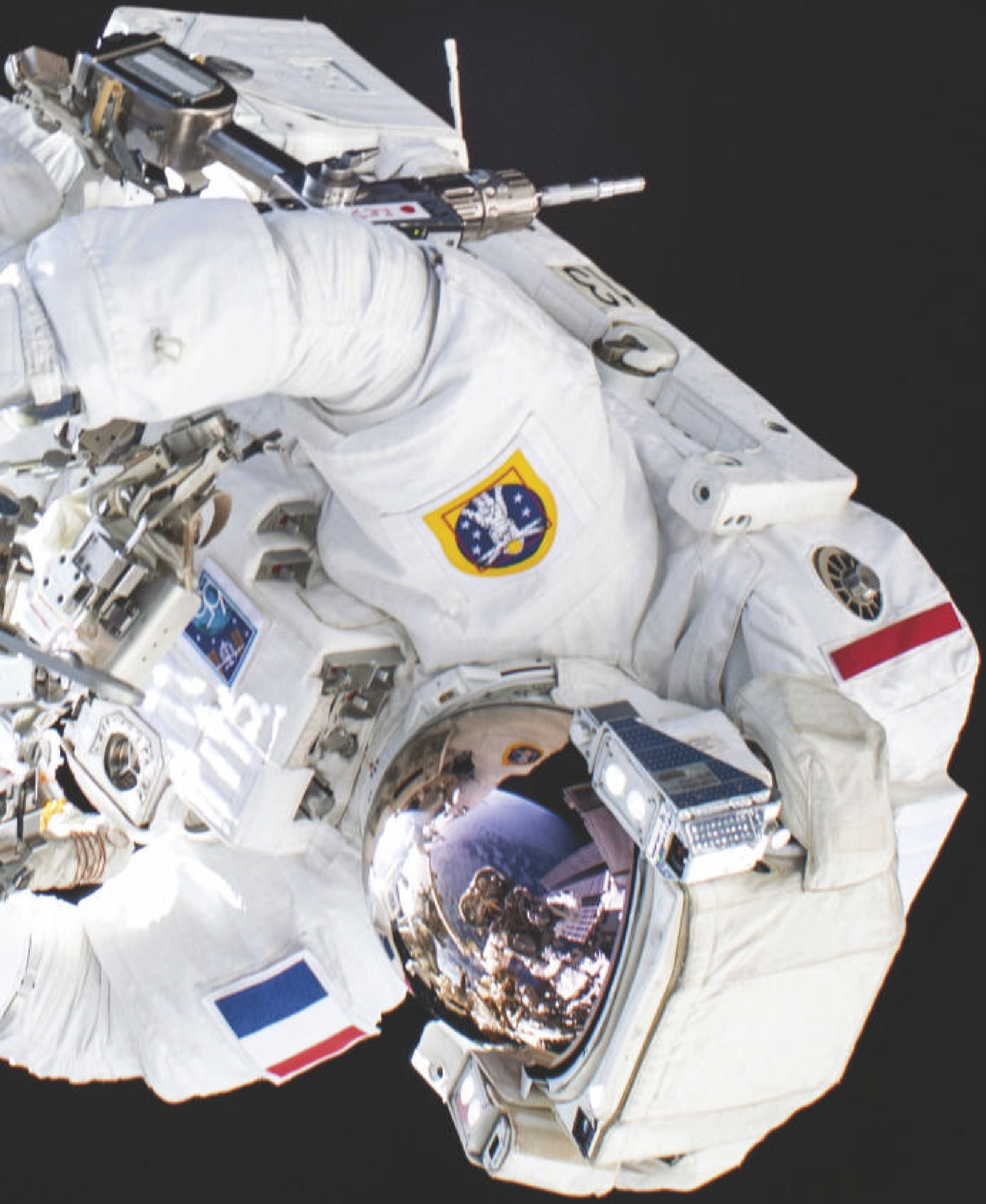
NEW AUGMENTED REALITY

Scan the QR code with your device's camera or download a free QR code reader app. Many iPhone and Android devices include these features

When you see the AR 'Scan Here' logo on the page, use your phone to scan the QR code, which looks like this

Hold your mobile device over the image and watch it come to life! Your device needs to be connected to the internet for this to function





16 JUNE 2021

Against the clock

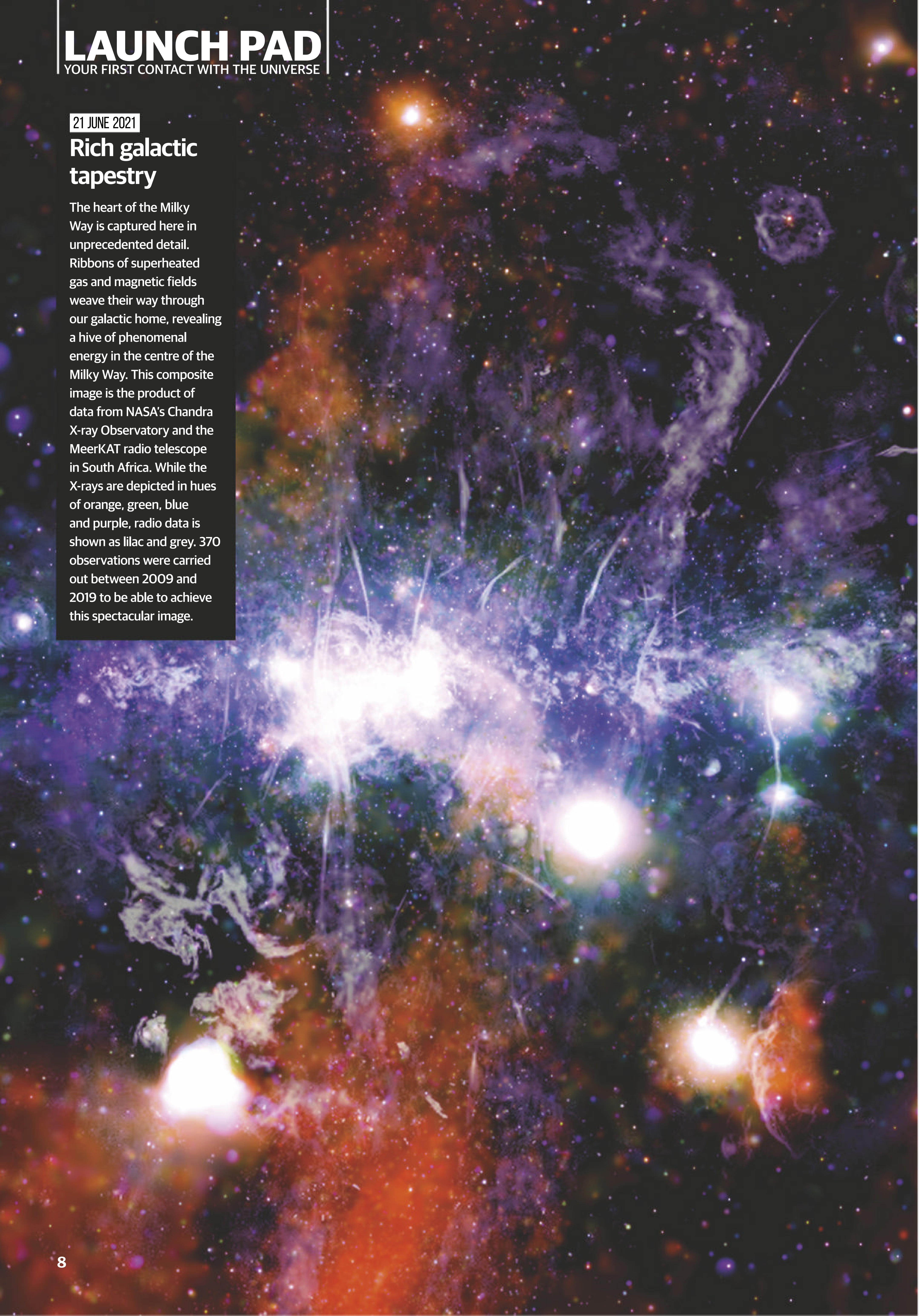
European Space Agency (ESA) astronaut Thomas Pesquet was manoeuvred by the Canadarm2 robotic arm during a spacewalk to install new roll-out solar arrays on the International Space Station. Pesquet was joined by NASA astronaut Shane Kimbrough on the spacewalk, which lasted just over seven hours. Despite initially making good progress, an interference issue with another piece of equipment prevented the pair unfolding the solar array fully, running out of time. The pair resumed their efforts four days later with a six-and-a-half hour spacewalk, and the arrays were successfully deployed.

© NASA

21 JUNE 2021

Rich galactic tapestry

The heart of the Milky Way is captured here in unprecedented detail. Ribbons of superheated gas and magnetic fields weave their way through our galactic home, revealing a hive of phenomenal energy in the centre of the Milky Way. This composite image is the product of data from NASA's Chandra X-ray Observatory and the MeerKAT radio telescope in South Africa. While the X-rays are depicted in hues of orange, green, blue and purple, radio data is shown as lilac and grey. 370 observations were carried out between 2009 and 2019 to be able to achieve this spectacular image.

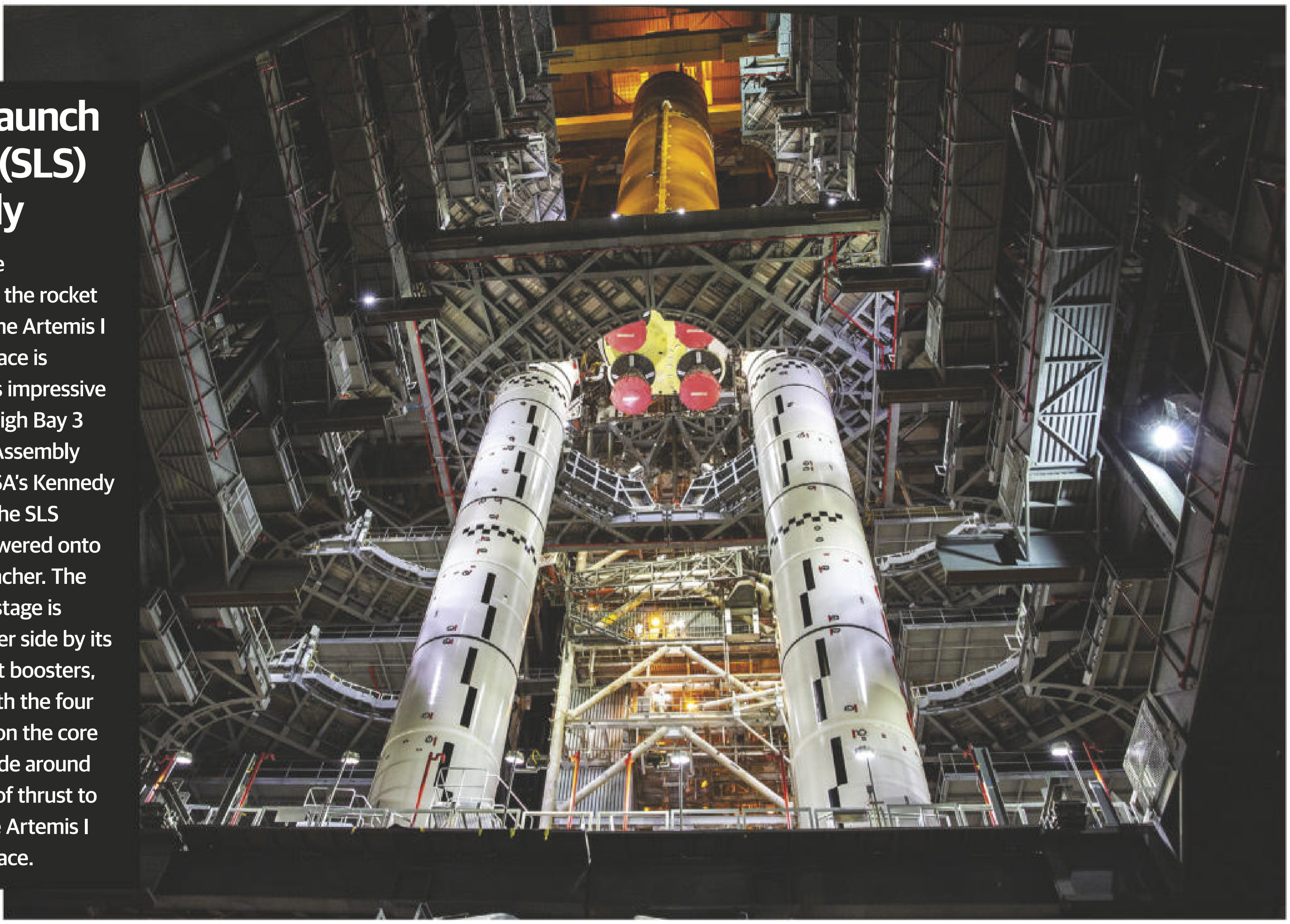


© ESA/Hubble & NASA

12 JUNE 2021

Space Launch System (SLS) assembly

The scale of the construction of the rocket that will send the Artemis I mission into space is captured in this impressive image. Inside High Bay 3 of the Vehicle Assembly Building at NASA's Kennedy Space Center, the SLS core stage is lowered onto the mobile launcher. The 53-tonne core stage is flanked on either side by its towering rocket boosters, which along with the four RS-25 engines on the core stage will provide around 4,000 tonnes of thrust to send the future Artemis I mission into space.

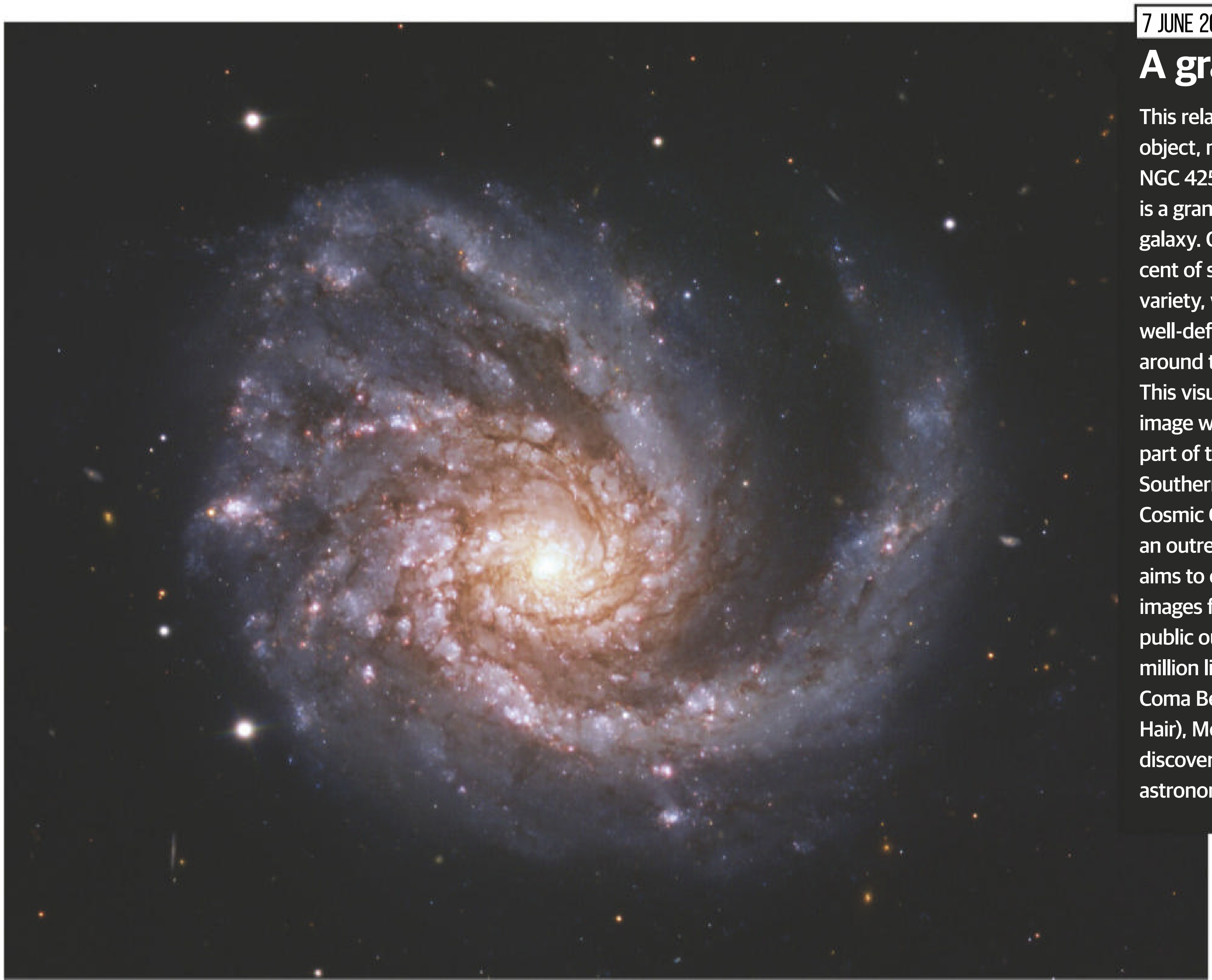


© NASA

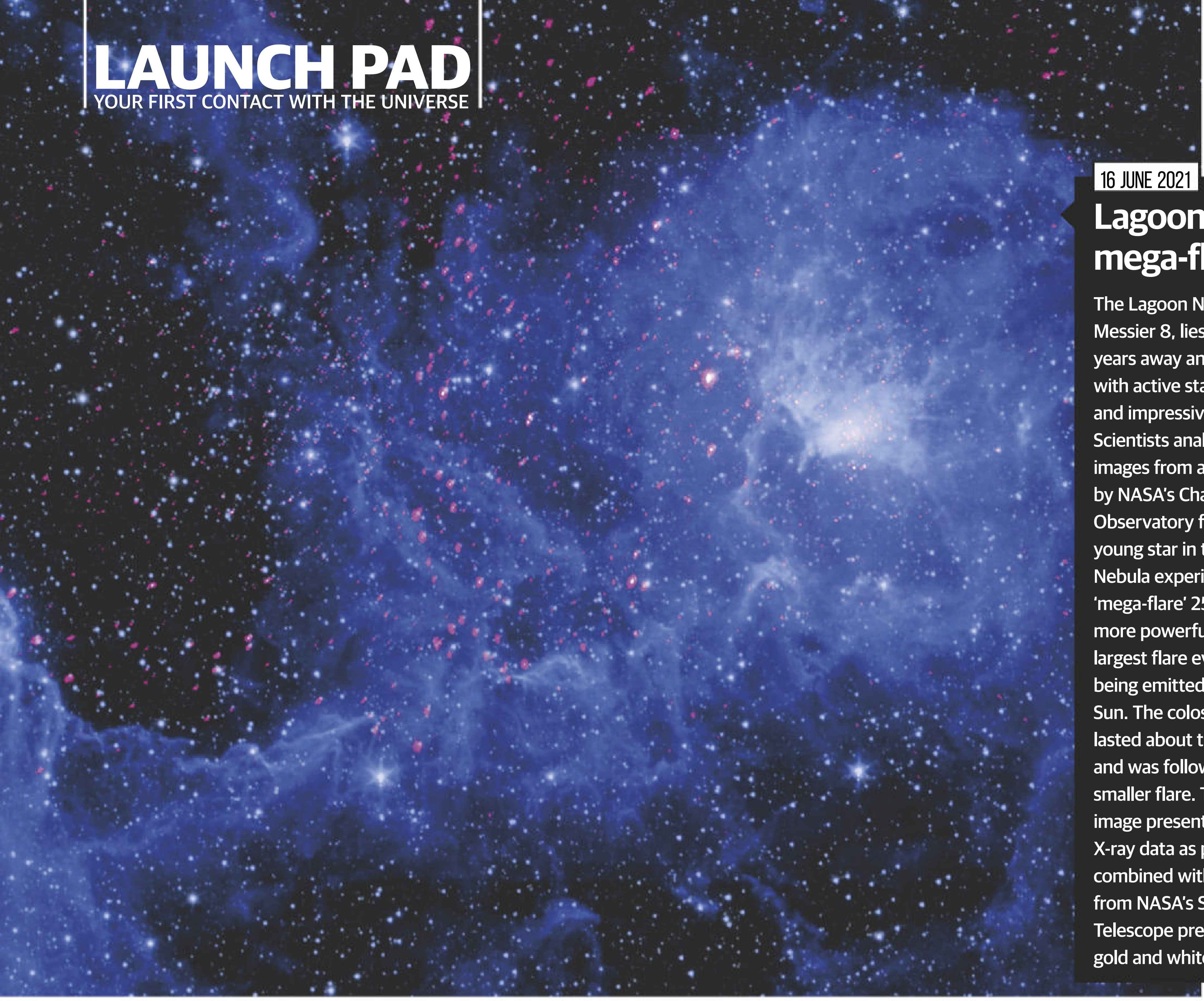
7 JUNE 2021

A grand design

This relatively unusual object, named both NGC 4254 and Messier 99, is a grand design spiral galaxy. Only about ten per cent of spirals are of this variety, with prominent, well-defined arms sweeping around the galactic centre. This visually arresting image was created as part of the European Southern Observatory's Cosmic Gems program, an outreach initiative that aims to capture spectacular images for education and public outreach. Located 55 million light years away in Coma Berenices (Berenice's Hair), Messier 99 was discovered in 1781 by French astronomer Pierre Méchain.



© ESO



16 JUNE 2021

Lagoon Nebula mega-flare

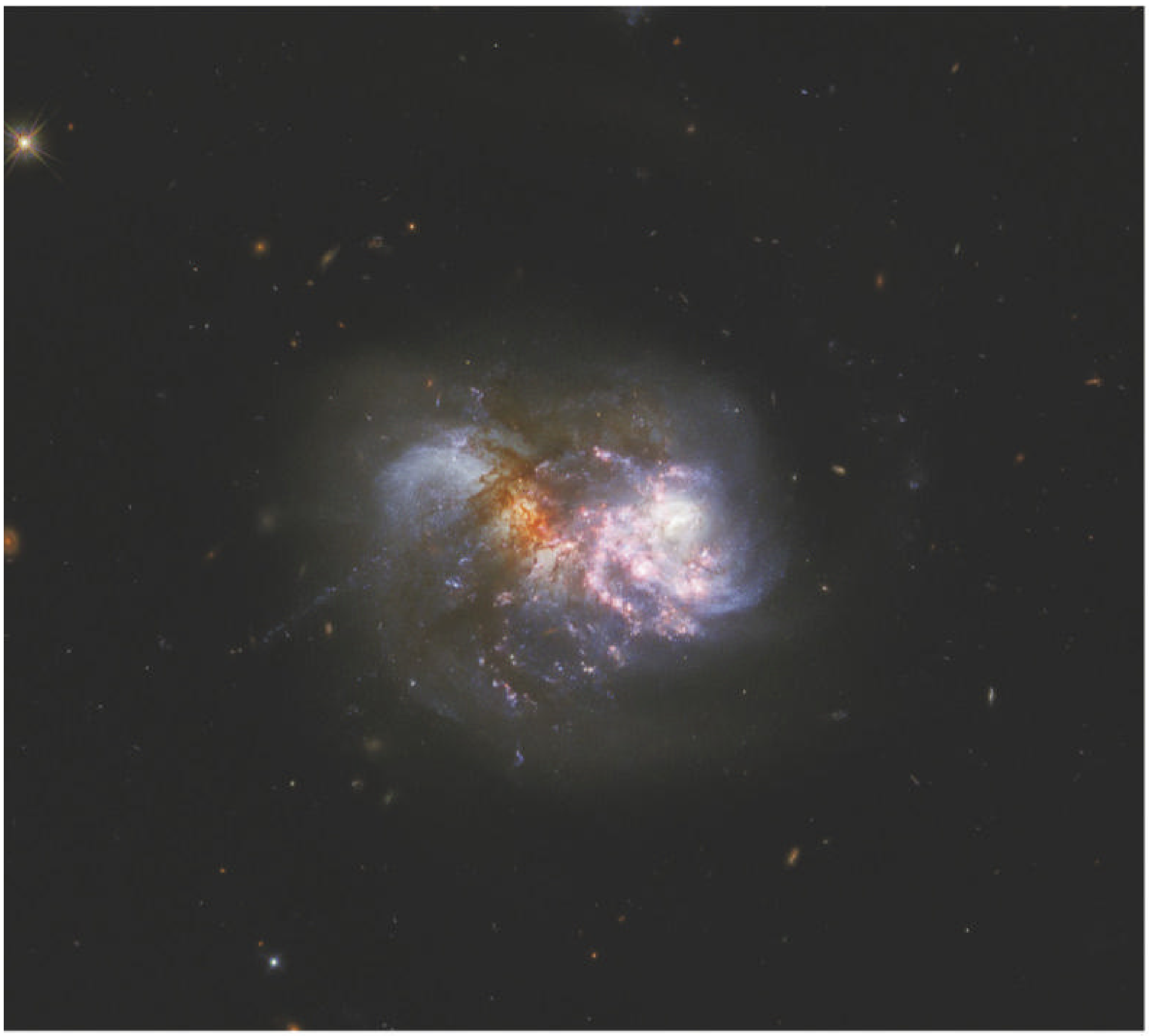
The Lagoon Nebula, or Messier 8, lies 4,100 light years away and is awash with active star formation and impressive 'mega-flares'. Scientists analysing X-ray images from a new survey by NASA's Chandra X-ray Observatory found that a young star in the Lagoon Nebula experienced a 'mega-flare' 250,000 times more powerful than the largest flare ever observed being emitted from our Sun. The colossal event lasted about three hours and was followed by a smaller flare. The composite image presents Chandra X-ray data as purple hues, combined with infrared data from NASA's Spitzer Space Telescope presented in blue, gold and white.

© NASA/JPL

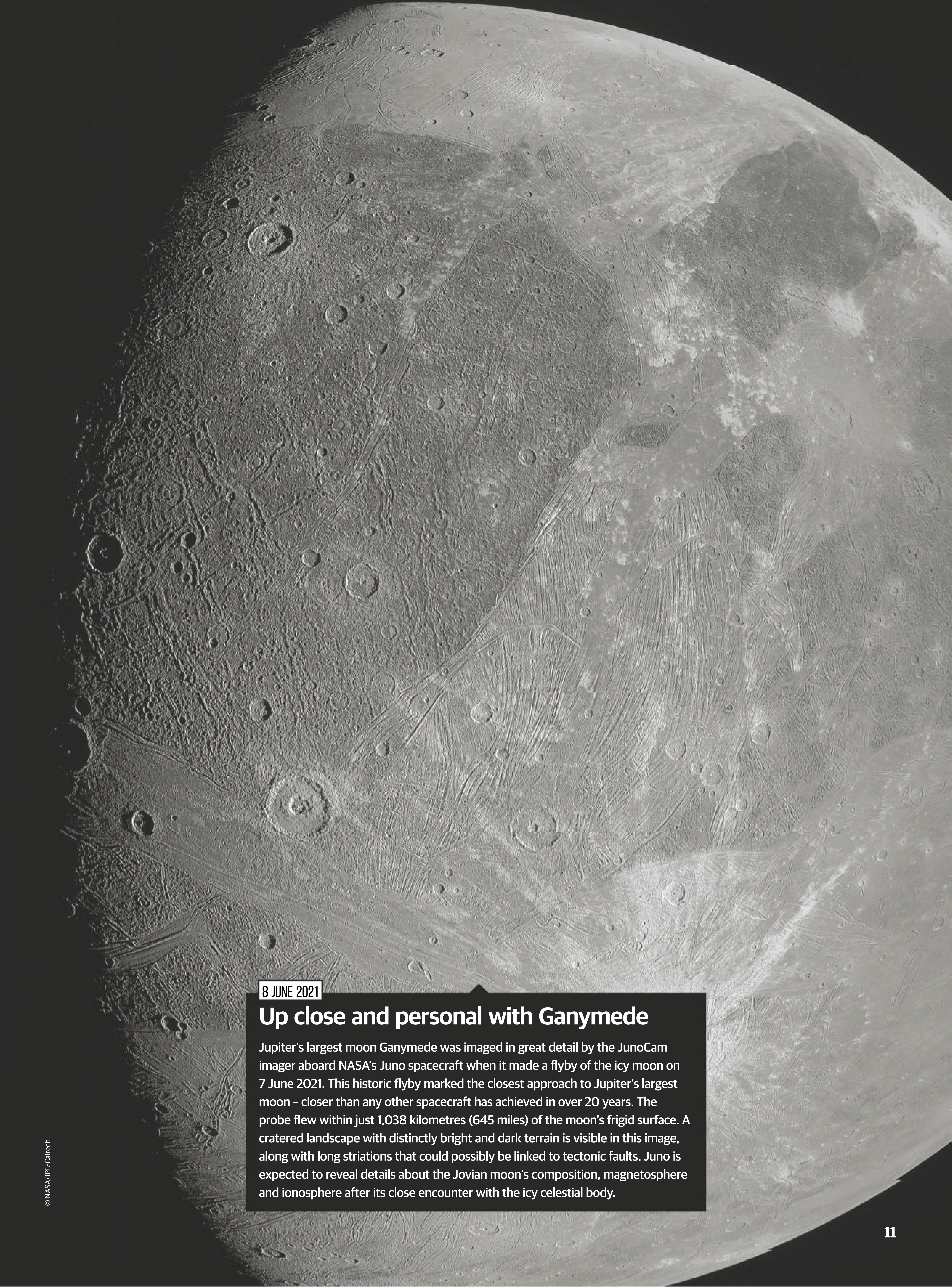
21 JUNE 2021

Cosmic clash

In the constellation of Cetus (the Whale) around 275 million light years away, a crash of cosmic proportions is well underway. Interacting galaxy pair IC 1623 is in the final stages of a galactic merger, which astronomers anticipate will result in a frenzied ignition of star formation. This updated image of the chaotic scene incorporates new data from Hubble's Wide Field Camera 3 in infrared and ultraviolet wavelengths. Future observations will be made with the James Webb Space Telescope to try and understand the processes at play during galactic mergers.



© ESA/Hubble & NASA



8 JUNE 2021

Up close and personal with Ganymede

Jupiter's largest moon Ganymede was imaged in great detail by the JunoCam imager aboard NASA's Juno spacecraft when it made a flyby of the icy moon on 7 June 2021. This historic flyby marked the closest approach to Jupiter's largest moon – closer than any other spacecraft has achieved in over 20 years. The probe flew within just 1,038 kilometres (645 miles) of the moon's frigid surface. A cratered landscape with distinctly bright and dark terrain is visible in this image, along with long striations that could possibly be linked to tectonic faults. Juno is expected to reveal details about the Jovian moon's composition, magnetosphere and ionosphere after its close encounter with the icy celestial body.

© NASA/JPL-Caltech

EARTH'S CORE IS GROWING 'LOPSIDED', AND SCIENTISTS DON'T KNOW WHY

Words by Brandon Specktor

There's a mystery brewing at the centre of the Earth. Scientists can only see it when they study seismic waves passing through the planet's solid-iron inner core. For some reason, waves move through the core significantly faster when they're travelling between the North and South Poles than when they're travelling across the equator.

Researchers have known about this discrepancy, known as seismic anisotropy, for decades, but have been unable to come up with an explanation that's consistent with the available data. Now, using computer simulations of the core's growth over the last billion years, a recent study offers a solution that finally seems to fit: every year, little by little, Earth's inner core is growing in a 'lopsided' pattern, with new iron crystals forming faster on the east side of the core than on the west side.

"The movement of liquid iron in the outer core carries heat away from the inner core, causing it to freeze," says Daniel Frost, a seismologist at the University of California, Berkeley. "This means the outer core has been taking more heat from the east side [under Indonesia] than the west [under Brazil]."

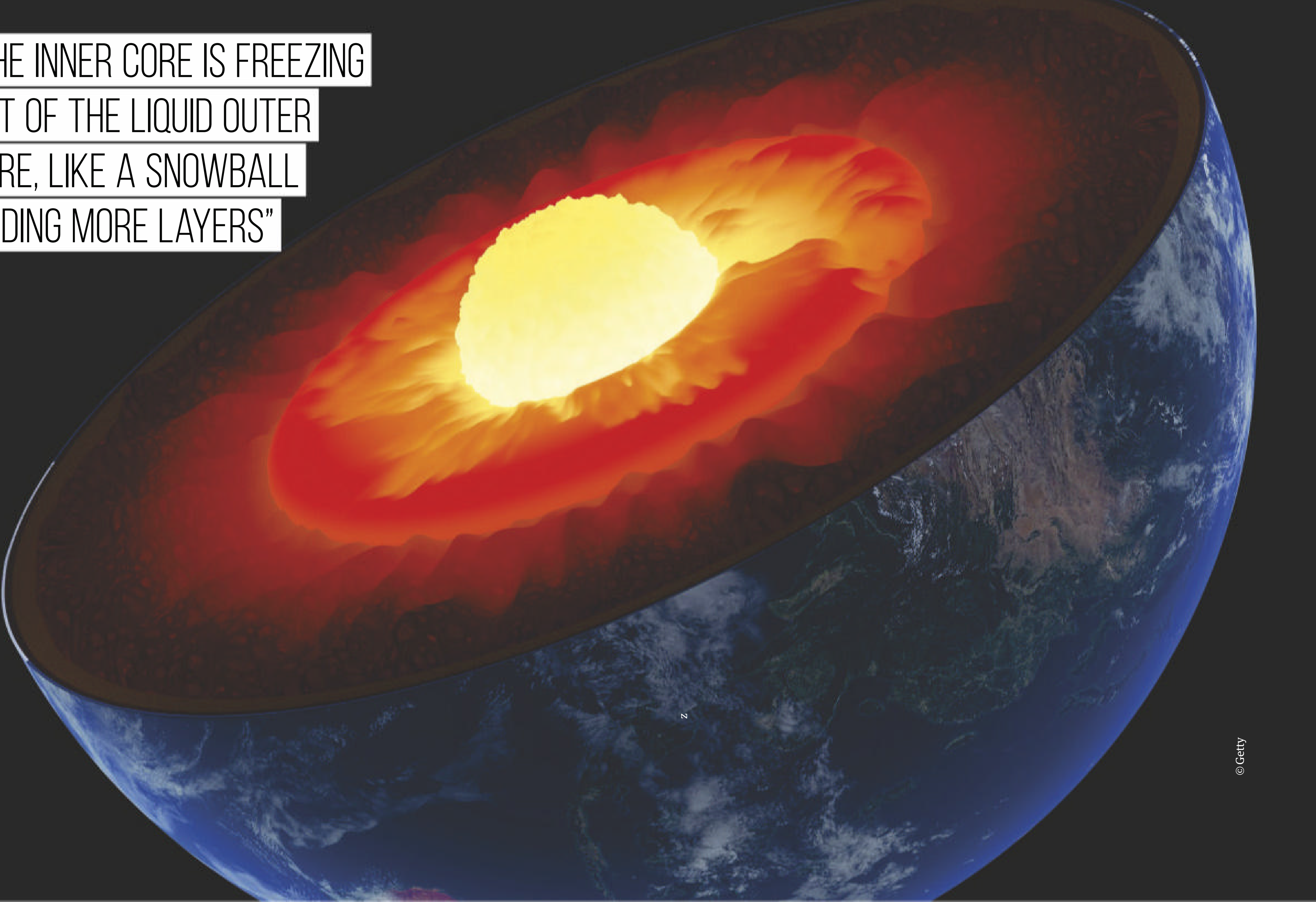
To visualise this lopsided growth in the core, imagine a tree trunk with growth rings radiating out from a central point, Frost said, but "the centre of the rings is offset from the centre of the tree" so that rings are spaced farther apart on the east side of the tree and closer together on the west side. A cross section of Earth's inner core might look similar to that. However, this asymmetric growth doesn't mean that the inner core itself is misshapen or at risk of becoming imbalanced.

On average, the inner core's radius grows evenly by about one millimetre every year. Gravity corrects for the lopsided growth in the east by pushing new crystals towards the west. There the crystals clump into lattice structures that stretch along the core's north-south axis. These crystal structures, aligned parallel with Earth's poles, are seismic superhighways that enable earthquake waves to travel more quickly in that direction.

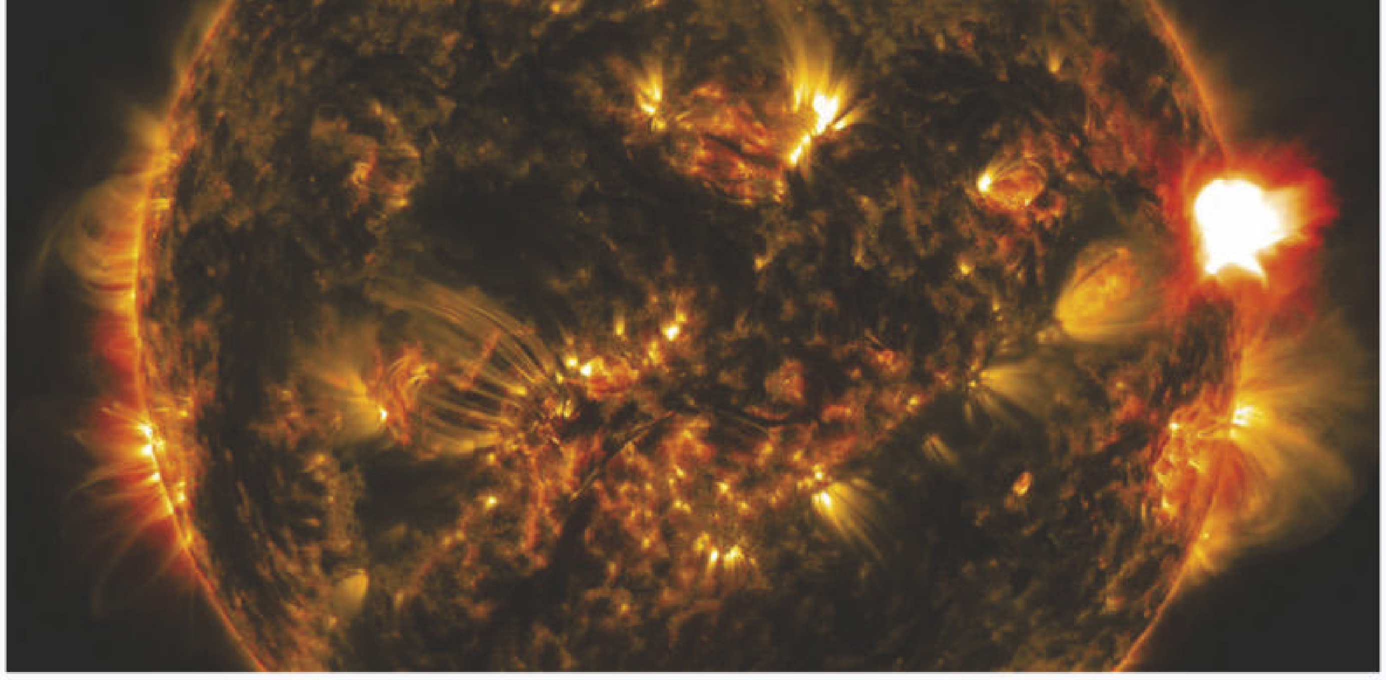
But what's causing this imbalance in the inner core? That's hard to say without looking at all the other layers of our planet, Frost said. "Every layer in the Earth is controlled by what's above it, and influences what's below it," he said. "The inner core is slowly freezing out of the liquid outer core, like a snowball adding more layers. The outer core is then cooled by the mantle above it, so to ask the question of why the inner core is growing faster on one side than the other might be asking the question of why one side of the mantle is cooler than the other."

Tectonic plates could be partially to blame. As cold tectonic plates dive deep below the Earth's surface at subduction zones - places where one plate sinks below another - they cool the mantle below. However, whether mantle cooling could impact the inner core is still a subject of debate.

"THE INNER CORE IS FREEZING OUT OF THE LIQUID OUTER CORE, LIKE A SNOWBALL ADDING MORE LAYERS"



© Getty



© NASA

'MISSING LINK' EXPLOSION ON THE SUN COULD UNRAVEL LONG-STANDING SOLAR MYSTERIES

Words by Chelsea Gohd

An explosion on the Sun is helping uncover new information about what causes powerful solar eruptions. In March 2016, scientists used NASA's Solar Dynamics Observatory and the Solar and Heliospheric Observatory, a joint mission of NASA and the European Space Agency (ESA), to observe an explosion on the Sun. The event showed characteristics of three different types of solar eruptions that usually happen separately, but occurred together this time. "This event is a missing link where we can see all of these aspects of different types of eruptions in one neat little package," said Emily Mason, a solar scientist at NASA's Goddard Space Flight Center in Maryland.

There are typically three different varieties of eruptions that can take place on the Sun: coronal mass ejections (CMEs), jets or partial eruptions. CMEs and jets are explosive and blast particles and energy out into the vacuum of space, whereas partial eruptions originate from the Sun's surface but don't make it all the way out into space – the material that erupts just falls back onto the Sun. The March 2016 event seems to have characteristics of all three different types of solar eruptions, so scientists think that they could all be caused by the same phenomenon. By finding the mechanism behind this event, they could explain the origins of all solar eruptions.

Above: The Sun's surface is always erupting

Below: The liver tissue was kept artificially 'alive' for 30 days

SCIENTISTS 3D PRINT HUMAN LIVER TISSUE IN A LAB AND WIN TOP PRIZES IN NASA CHALLENGE

Words by Chelsea Gohd

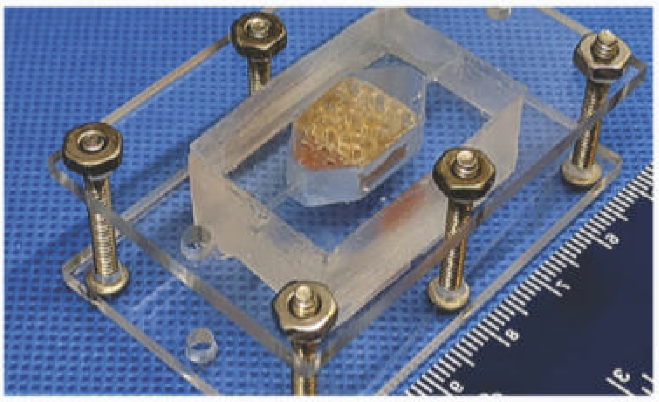
Scientists have grown liver tissue capable of functioning for 30 days in the lab as part of NASA's Vascular Tissue Challenge. In 2016 NASA put forth this competition to find teams that could 'create thick, vascularised human organ tissue in an in-vitro environment to advance research and benefit medicine on long-duration missions and on Earth'. On 9 June the agency announced two winners of the challenge.

The teams, both made up of scientists from the Wake Forest Institute for Regenerative Medicine (WFIRM) in North Carolina, won first and second place in the competition with different approaches to creating lab-grown human liver tissue.

The winning teams both used 3D-printing technologies to create their tissue. As dictated in the challenge rules, the teams had to keep their tissues 'alive' for 30-day trials. But to engineer tissue and have it 'survive,' the teams had to figure out how to move nutrients and oxygen through their creation and how to remove waste.

This process, known as perfusion, is done by blood vessels in organic, living tissues, but this is extremely tricky to replicate artificially. Using different materials and 3D-printed designs, the two teams each made different gel-like frameworks for their tissues that included channels that oxygen and nutrients could run through. The teams were able to get nutrients to flow through their artificial blood vessels without leaking.

The team that won first place, called team Winston, is the first team to complete its trial with the engineered tissue under the challenge rules and will receive $300,000 (£213,000) and the opportunity to further this work aboard the International Space Station.



© Wake Forest Institute for Regenerative Medicine

HOW IT WORKS
subscription offer
FROM
£2.20
PER
ISSUE!

PRINT
£3.28 PER ISSUE!

DIGITAL
£2.20 PER ISSUE!

PRINT & DIGITAL
£3.67 PER ISSUE!

This offer is **only** available via our online shop
www.magazinesdirect.com

EARTH'S AURORA ORIGIN MYSTERY SOLVED BY 'SURFING' ELECTRONS

Words by Daisy Dobrijevic

© Getty

Earth's aurorae are caused when electrons emitted from the Sun hurtle towards Earth and are funnelled down Earth's magnetic field lines, where they collide with oxygen and nitrogen molecules in the ionosphere - the upper atmosphere between 80 and 600 kilometres (50 and 370 miles). The absorption of energy by these ions causes them to move to an 'excited' high-energy state. To relax, the molecules reradiate the energy as light, producing impressive auroral displays.

Though scientists understand what causes aurorae, a mystery remains - just how do these electrons accelerate to speeds of up to 72 million kilometres (45 million miles) per hour on the last stretch of their journey into the ionosphere? Scientists have now discovered that the electrons catch a wave - specifically Alfvén waves - that travel along magnetic field lines above aurorae. Scientists simulated conditions in the Earth's aurora magnetosphere, then launched Alfvén waves down a 20 metre (65 feet) chamber and recorded whether electrons within the chamber were affected by the Alfvén waves.

"Measurements revealed this small population of electrons undergoes 'resonant acceleration' by the Alfvén wave's electric field, similar to a surfer catching a wave and being continually accelerated as the surfer moves along with the wave," said Gregory Howes, an associate professor of physics at the University of Iowa. This provides the first direct evidence that electrons surfing on Alfvén waves create aurora.

Above: Electrons 'surf' Alfvén waves to reach their high speeds

BOULDERS ON ASTEROID RYUGU ARE SURPRISINGLY FLUFFY, HAYABUSA2 FINDS

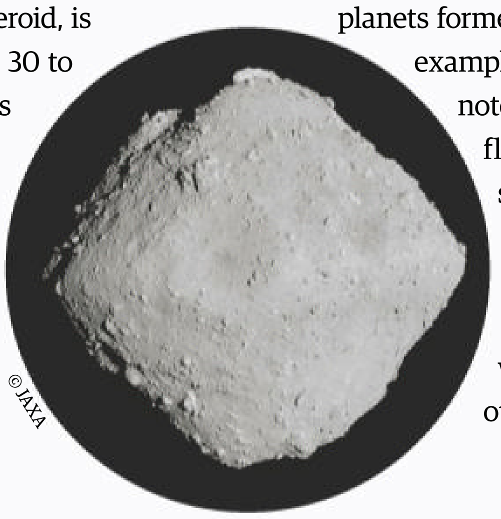
Words by Charles Q. Choi

Boulders on asteroids can be three-quarters hollow or more, a discovery that could help yield insights on how Earth and other planets formed. The earliest stage of planetary formation started with building blocks known as planetesimals, chunks of rock ranging in size from asteroids to dwarf planets. Research suggested planetesimals began as very porous, fluffy clumps of dust that heat, gravity and impacts compacted over time.

Japan's Hayabusa2 spacecraft found that Ryugu, a diamond-shaped near-Earth asteroid, is covered with rocks that are about 30 to 50 per cent porous. Now scientists have found that those boulders may be more than 70 per cent empty space, or about as porous as prior work suggested ancient planetesimals were, suggesting the rocks may contain remnants of the early Solar System.

The researchers noted that Ryugu's hotspot boulders are about as porous as the bodies of comets. Prior work noted that comets are likely remnants of the original planetesimals, and now scientists are suggesting that Ryugu's hotspot boulders may similarly be remnants of ancient planetesimals which cosmic impacts blasted out from under Ryugu's surface.

Uncovering details about the original nature of planetesimals could shed light on how the planets formed after the Sun was born. For example, the scientists previously noted that if planetesimals are as fluffy as researchers increasingly suspect, then they might have crumbled more easily during impacts, making them less likely to eject fragments with great force to shatter other asteroids.



© JAXA

Left: Hayabusa returned asteroid samples in 2020

Right: The 3D-printed rocket could massively cut launch costs

IN COOPERATION WITH SPACE.com

RELATIVITY SPACE UNVEILS FULLY REUSABLE, 3D-PRINTED TERRAN R ROCKET

Words by Mike Wall

A fully reusable, 3D-printed rocket will be launching satellites into orbit three years from now - if all goes according to plan. Relativity Space has revealed details of Terran R, a new two-stage rocket expected to launch for the first time in 2024.

The engines, which burn liquid oxygen and methane, are 3D printed, just like the rest of the rocket. This manufacturing strategy allows Relativity Space to build rockets with 100 times fewer parts than those of its competitors and churn out a completed vehicle in less than 60 days.

Terran R will be 66 metres (216 feet) tall by 4.9 metres (16 feet) wide, with the ability to lift more than 20,000 kilograms to low-Earth orbit.

The entire rocket - the first stage, the second stage and the payload fairing, which protects satellites during launch - are also said to be reusable. "There's an organic relationship between 3D printing and reusability, and it gives us an unparalleled advantage to design the best fully reusable rocket possible," said Tim Ellis, Relativity Space co-founder and CEO.

© Relativity Space

WIN

MEADE POLARIS 130 MD

WORTH £250

Kick-start your stargazing hobby with this month's competition

This month we're offering you the chance to win a telescope kit which comes complete with everything you need to begin touring the night sky in one box. With its five-inch aperture, the Meade Polaris 130 delivers exquisite views of a wide selection of night-sky objects, from Solar System targets to a variety of deep-sky objects such as the Andromeda Galaxy and Orion Nebula.

A stable German equatorial mount with slow-motion controls enables easy tracking, allowing you to keep objects in your field of view as they move across the night sky, while a motor drive allows multi-speed tracking of the Moon, planets and stars. A stainless-steel tripod with accessory tray – to hold the supplied 6.3mm, 9mm and 26mm three-element eyepieces and 2x Barlow lens – provides the finishing touch to a sturdy and capable instrument.

A breeze to set up, this reflector offers good portability, offering you the versatility of transporting it the short distance to your back garden or further afield to your favourite dark-sky location. The supplied AutoStar Suite planetarium software contains information on over 10,000 objects to ensure that you're free to tour the night sky whatever the weather!

MEADE INSTRUMENTS

To be in with a chance of winning, answer this question:

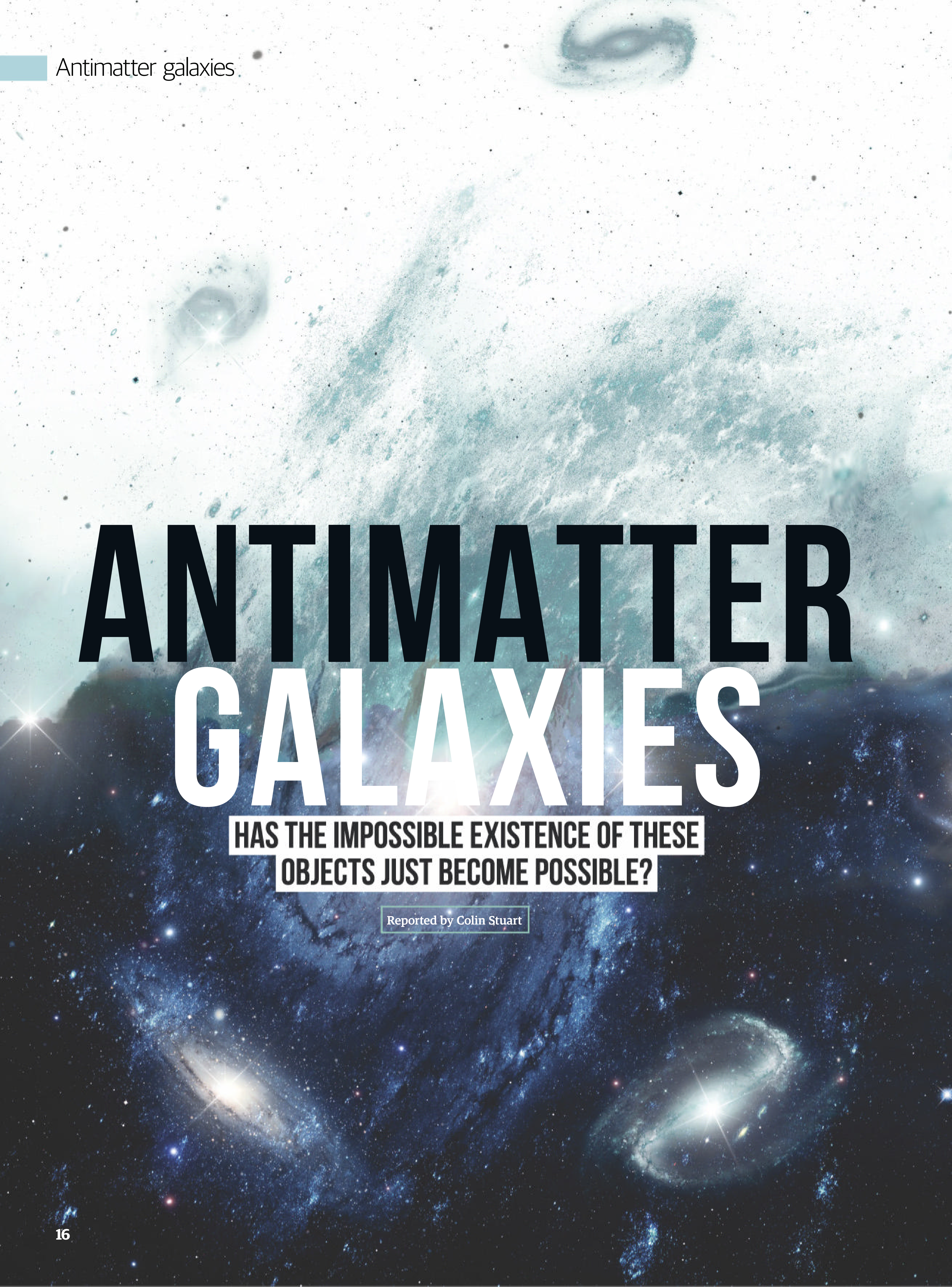
In which constellation is the Lagoon Nebula (Messier 8)?

A: Capricornus **B:** Orion **C:** Sagittarius

Competition ends on 12 August 2021

Enter online at **surveymonkey.co.uk/r/AAS119COMP**

Visit the website for full terms and conditions at **futureplc.com/terms-conditions**



ANTIMATTER GALAXIES

HAS THE IMPOSSIBLE EXISTENCE OF THESE OBJECTS JUST BECOME POSSIBLE?

Reported by Colin Stuart

You shouldn't exist. That you do suggests something is very wrong with our best theories in physics. Yet there is a way to both explain your existence and save theorists' blushes: if bizarre entities called antimatter galaxies also exist.

In the beginning there was nothing, only energy. Our universe burst into existence 13.8 billion years ago in the Big Bang, and soon some of the energy was converted into particles. The kind of particles that are the building blocks of atoms, which in turn are the building blocks of you. We call this stuff matter. Except that's only half the story. The process of converting energy into stuff is called pair production. Even the name hints at a deeper reality. It creates pairs of particles. Every particle of new matter is joined by another of antimatter.

Antimatter sounds futuristic, and you'll often see it deployed in science fiction. It may sound made

> "OUR UNIVERSE CAME TO CONTAIN SO MUCH MORE MATTER THAN ANTIMATTER"
>
> DAN HOOPER

© Tobias Roetsch

ANTIMATTER GALAXY FORMATION

Antimatter galaxies would form in just the same way as matter galaxies

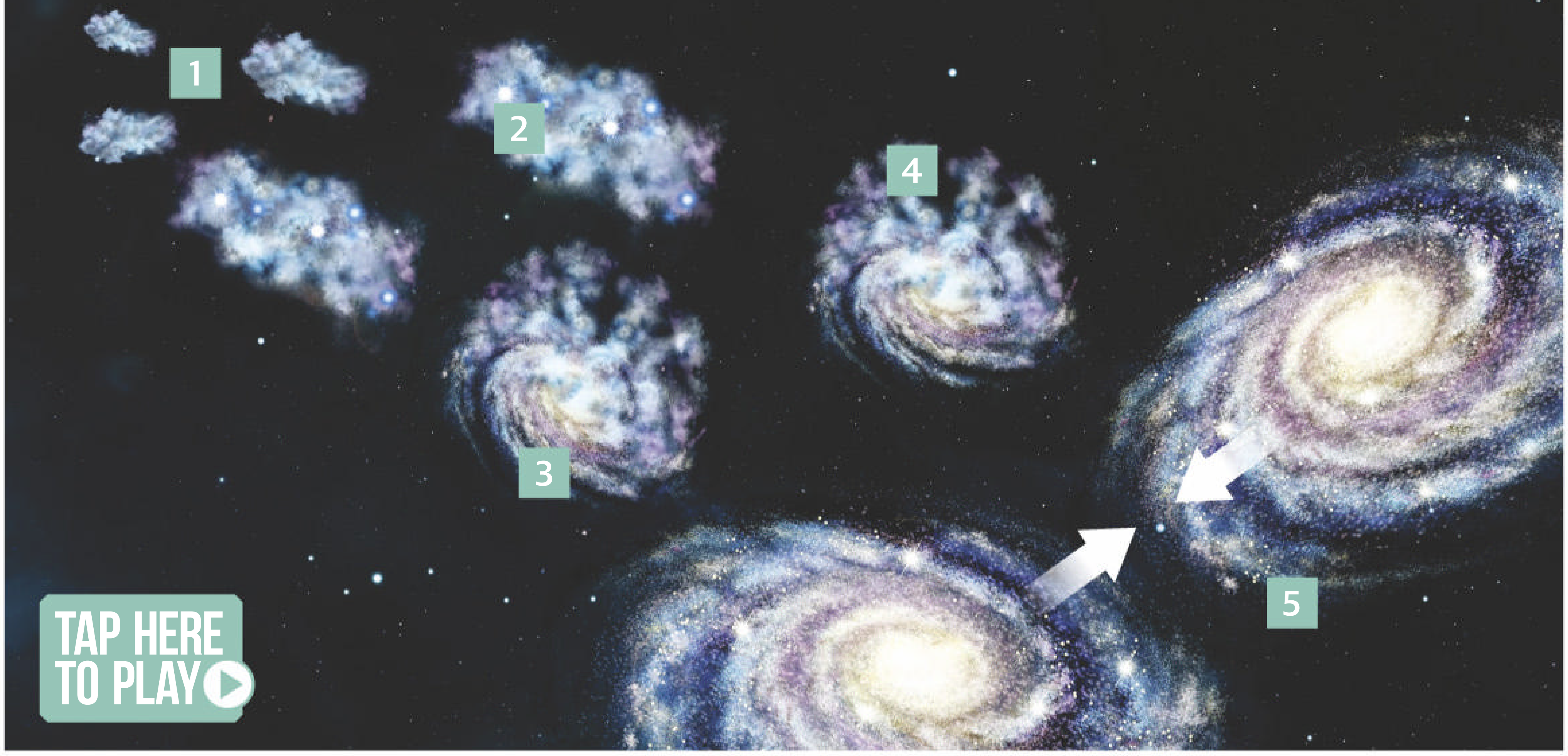
1 CLUMPING First dark matter clumps together to form a seed.

2 COLLAPSING Clouds of antimatter collapse under gravity to form antistars.

3 FLATTENING Collapse quickens spin, so the disc of antistars rotates and flattens.

4 MULTIPLYING New antistars begin to form, further populating the galaxy.

5 MERGERS The antigalaxy may merge with another and increase in size.



up for dramatic effect, but we know for certain that it exists. A banana, for example, contains traces of radioactive potassium. As the potassium decays it spits out a particle called a positron every 75 minutes. A positron is the antimatter partner of the more familiar electron. It has identical properties, save for the opposite electric charge. It's different from a proton – which also has the opposite charge to an electron – but is considerably heavier.

Your fruit bowl isn't the only source of antimatter on Earth. The Fermi Space Telescope has spotted beams of antimatter launched by thunderstorms acting as giant particle accelerators. We also make antimatter in our own particle accelerators, such as the Large Hadron Collider (LHC) and the Fermilab Tevatron. Yet making a single, usable antiproton requires 1 million ordinary protons and at least 26 million times the energy of the antiproton itself. It won't come as a surprise that the total amount of antimatter we've created in particle accelerators runs to just a few tens of nanograms – 1 nanogram is a billionth of a gram, about the same mass as a single human cell.

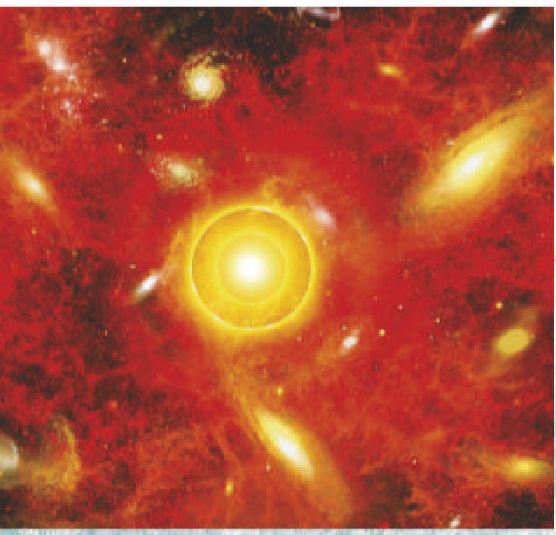
But really there shouldn't be any matter or antimatter at all. The opposite process to pair production – where a particle of matter meets its antimatter equivalent and they recombine – is called annihilation. The most common annihilation is when an electron meets a positron and they convert back into energy in the guise of gamma rays, the most energetic form of light.

If matter and antimatter were created in equal quantities after the Big Bang, then there has been more than enough time since for it all to annihilate. There should be no stars, no planets and definitely no radioactive bananas.

We can explain away this discrepancy if pair production is an asymmetrical process, but that goes against the known laws of physics, which are inherently symmetrical. Imagine that for every billion antimatter particles created after the Big Bang, a billion and one matter particles appeared. Over time, all of the antimatter would annihilate with almost all of the matter, leaving a very tiny residue of matter left over. It's that residue that forms everything in the vast and sprawling universe we see today, including you.

There's evidence of this asymmetry from various experiments with subatomic particles. Back in the 1960s, we noticed something odd was going on with particles called kaons. "Physicists expected that kaons could transform into antikaons and vice versa, but were surprised to learn that these processes don't happen in both directions at the same rate," says Dan Hooper from the University of Chicago. Nature seems to prefer kaons.

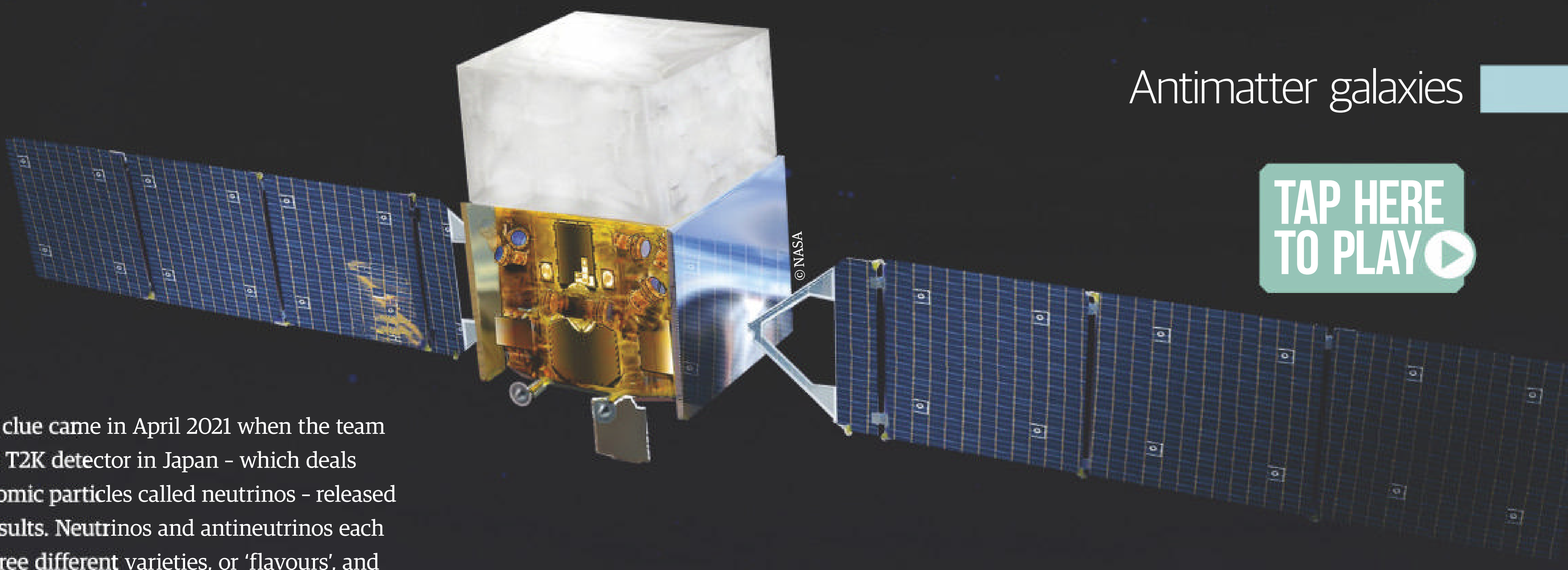
It's not the whole answer, however. "[It's] not enough to explain how our universe came to contain so much more matter than antimatter," Hooper says. "Some other unknown process(es) must exist that made this possible."



Left: Some of the energy of the Big Bang was soon turned into particles and antiparticles

© Getty

TAP HERE TO PLAY



© NASA

Another clue came in April 2021 when the team behind the T2K detector in Japan - which deals with subatomic particles called neutrinos - released its latest results. Neutrinos and antineutrinos each come in three different varieties, or 'flavours', and routinely switch between them. The team found that these transitions happen at a higher rate for neutrinos compared with antineutrinos. More evidence that matter and antimatter are not as symmetrical as we'd like to think.

Then, in June 2021, physicists using data from the LHC discovered something new about another kind of subatomic particle called the charm meson. They found that it can spontaneously switch between its matter and antimatter versions. Now they can experiment further to see if, like the kaon and the neutrino, the switch happens more often one way than the other. Doing so would provide yet more valuable hints as to where all the antimatter went.

Part of the problem with understanding antimatter is that its existence is so fleeting. Once created in particle accelerators, it quickly decays into something else or annihilates with matter. Yet slowly but surely, we're starting to understand more. In March 2021, a team led by Christopher Baker at Swansea University revealed it'd invented a new device that creates, confines and cools antihydrogen using lasers. It gives researchers more time to study the properties of antimatter before it disappears. "Our experiments could be a significant step in solving the mystery of the missing antimatter in our universe," Baker's colleague Niels Madsen wrote in a recent piece.

There's another option that would maintain the sacred symmetry of our current best theories. It's possible that matter and antimatter were created equally, but then separated somehow before they were ever able to recombine. Maybe we live in the matter-dominated part of the universe and there's another distant part dominated by antimatter. "If this were true, then there should also exist other galaxies made of antimatter," says Hooper. "In almost every respect these antimatter galaxies would look and behave just like ordinary galaxies - containing stars, gas, dust and planets, all made of antimatter." There could even be antibananas spitting out electrons instead of positrons.

The big problem with this idea is that it's likely the antimatter would come into contact with matter at some stage. An antimatter galaxy

> "ANTIMATTER GALAXIES WOULD LOOK AND BEHAVE JUST LIKE ORDINARY GALAXIES"
>
> DAN HOOPER

Above: Fermi has been used to spot antimatter in thunderstorms and search for antistars

Below: If normal and antimatter galaxies collided, they would annihilate each other

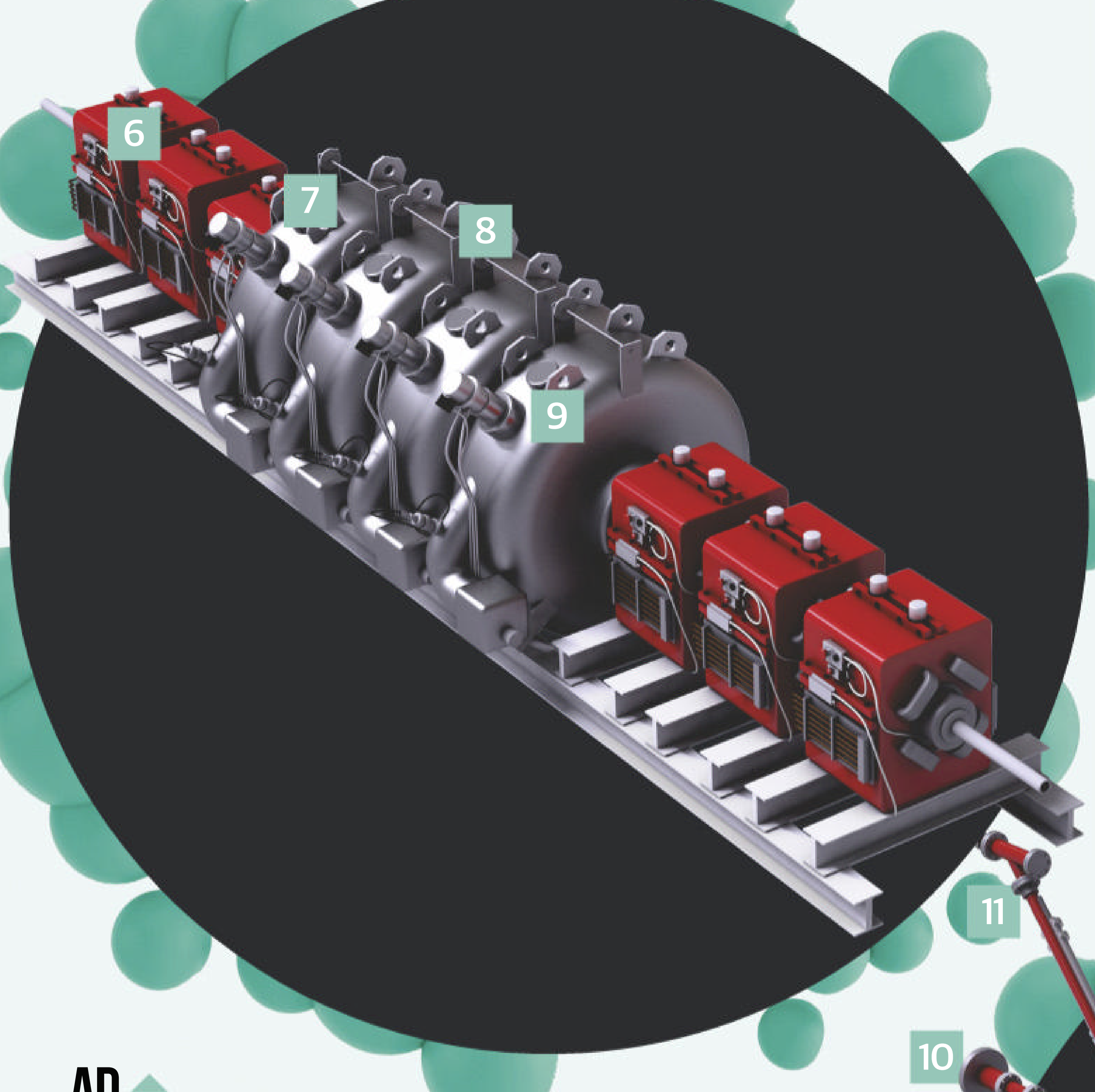
© Gemini Observatory, GMOS-South, NSF

Left: Antimatter is created in particle accelerators, such as Fermilab near Chicago

© Getty

LARGE HADRON COLLIDER

Inside the most famous particle accelerator



AD

The Antiproton Decelerator is a source of antiprotons for use in other antimatter experiments at the LHC

BEAM TO BLOCK

6 A powerful proton beam is fired into a block of metal.

PARTICLE PRODUCTION

7 A shower of particles is produced, including antiprotons.

MAGNETIC FORCE

8 A ring of magnets bends and focuses some of the antiprotons.

ELECTRIC OBTRUSION

9 Strong electric fields slow the antiprotons down.

AEgIS

The Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy looks at how Earth's gravity affects antihydrogen

FROM THE AD

10 Antiprotons enter the device from the Antiproton Decelerator.

HIT THE TARGET

11 Shooting positrons onto a target produces positronium atoms.

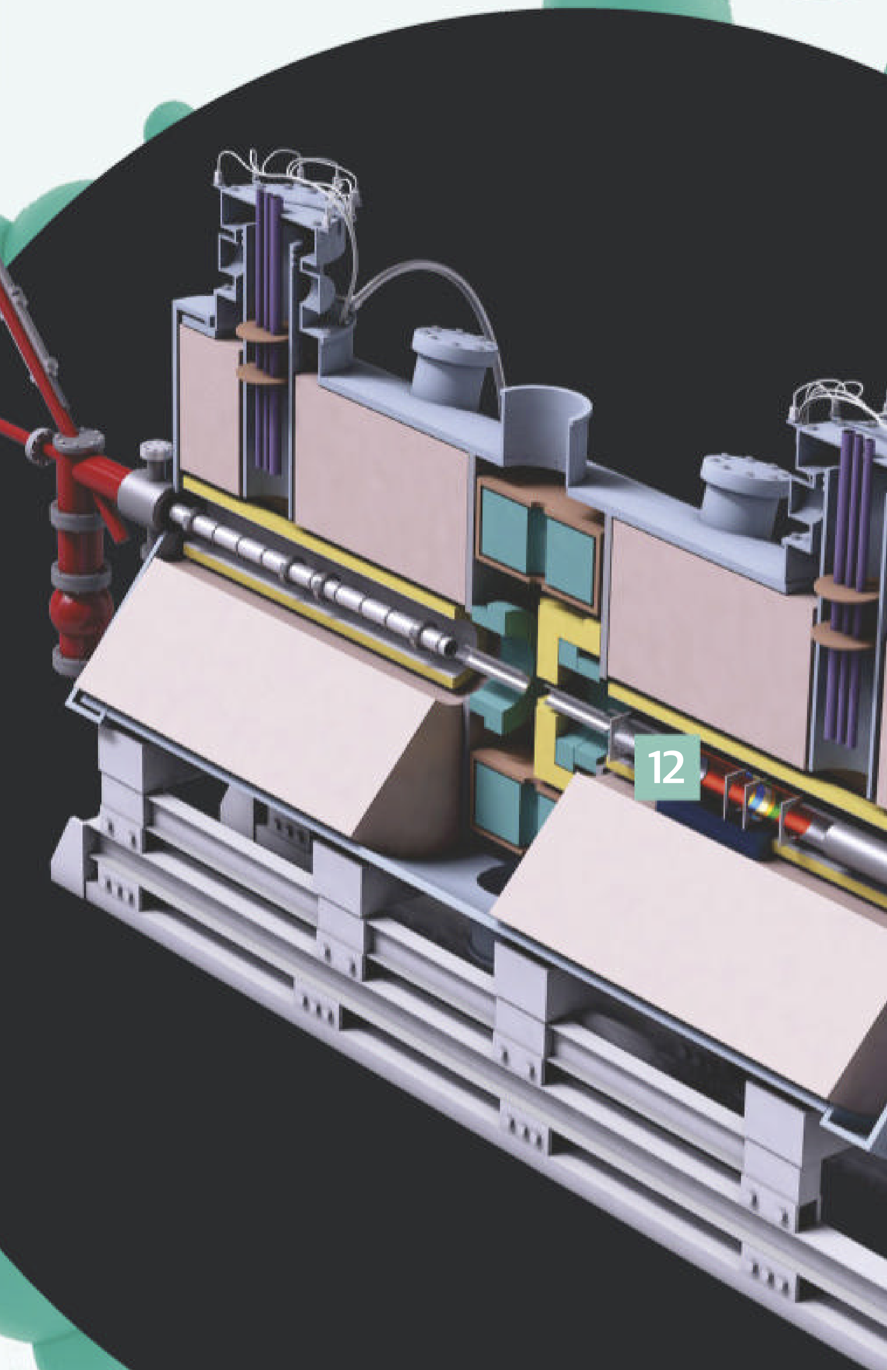
COME TOGETHER

12 These are combined to make horizontally travelling antihydrogen atoms.

FORCE OF GRAVITY

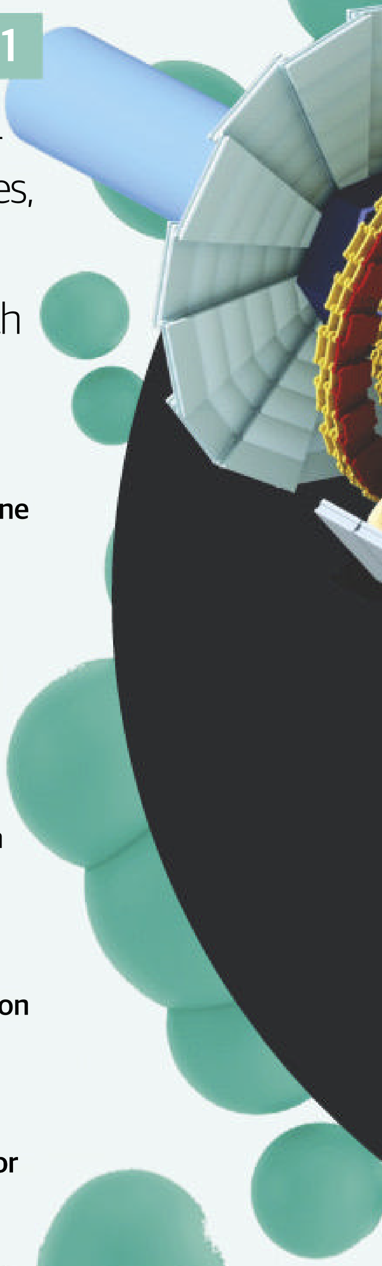
13 A detector helps measure the deflection of antihydrogen due to gravity.

TAP HERE TO PLAY



ALPHA

The Antihydrogen Laser PHysics Apparatus makes, captures and studies atoms of antihydrogen and compares them with hydrogen atoms



1 ANTIPROTONS

Antiprotons enter through one end of the device.

2 POSITRONS

Positrons enter through the other end.

3 COLLISION COURSE

Antihydrogen is made when they collide.

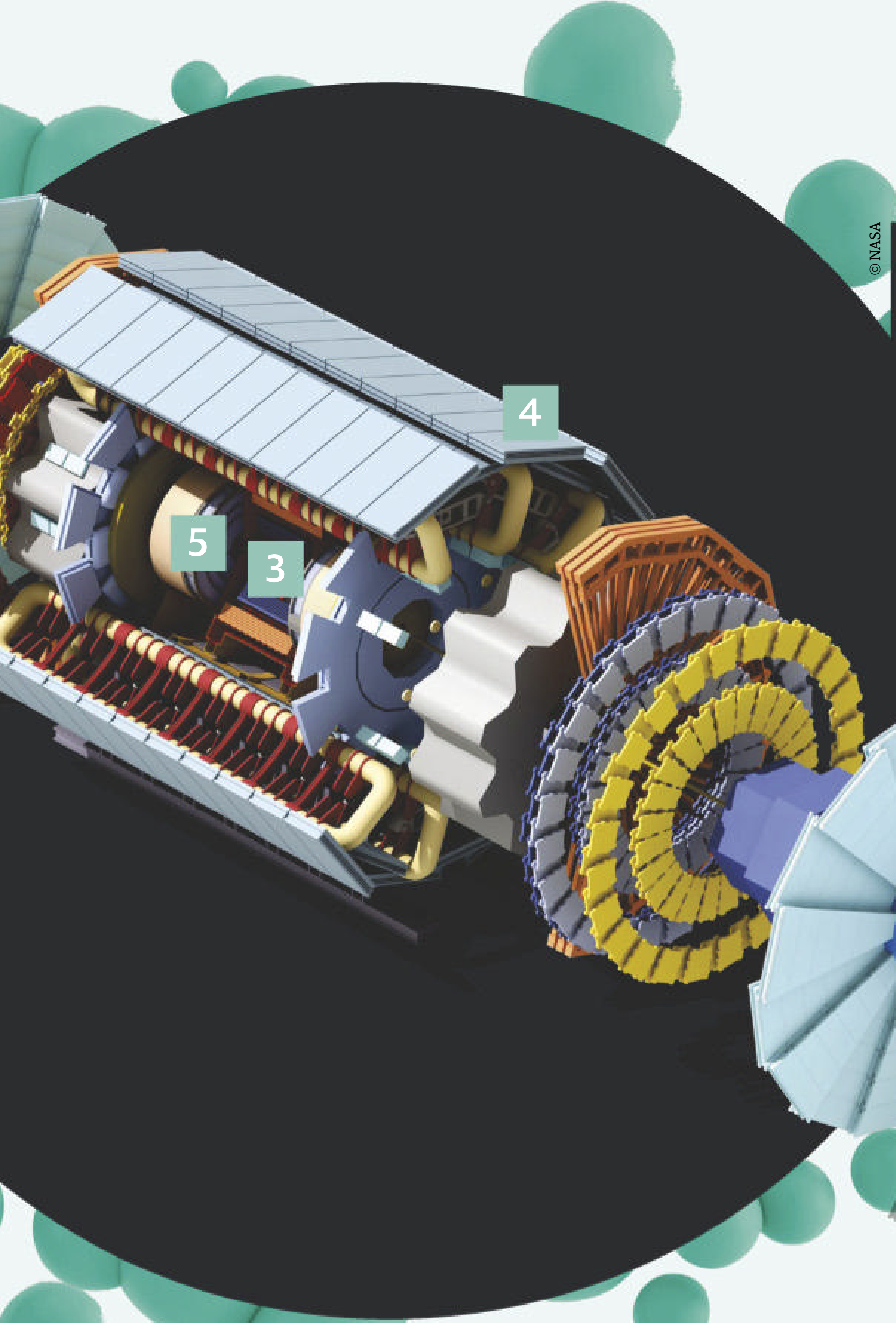
4 WALLED IN

The device delays annihilation with the walls of the detector.

5 PRESERVATION

Antihydrogen can be kept for 16 minutes and studied.

x3 illustrations © Adrian Mann



© NASA

Above: Russian scientists examined the possibility that these stars were in fact antistars

colliding with a matter galaxy, for example, would create an unmissable cacophony of gamma rays. Yet we've never seen such a distinctive signal. "For this reason it doesn't seem plausible that our universe contains equal amounts of matter and antimatter," says Hooper.

That doesn't rule out antimatter galaxies entirely. Instead it suggests that if they do exist, they must be rare. It would help if we knew if antistars exist. We've never seen one, but what would they look like if we could? In many ways an antimatter star would look no different to the stars that blaze in the night sky. Stars create light by turning hydrogen into helium in a process called nuclear fusion. In fact, the Sun converts 620 million tonnes of hydrogen into 616 million tonnes of helium each and every second. The missing 4 million tonnes is turned into sunshine. An antistar would create light by churning antihydrogen into antihelium. Crucially, the light produced would be identical in both cases. Light is made up of particles called photons, and the photon is its own antiparticle - there is no antiphoton.

Antistars would still spew antihydrogen and antihelium into space, just as the Sun emits normal hydrogen and helium through the solar wind. So imagine the excitement when the AMS-02 experiment strapped to the International Space Station detected eight particles of antihelium back in 2017. "The easy way to produce them would be the existence of a nearby antistar," says Simon Dupourqué from L'Institut de Recherche en Astrophysique et Planétologie in Toulouse, France.

But if the light created by antistars is identical to ordinary stars, how could we find the antistar that's potentially creating this antihelium? By

OTHER LHC EXPERIMENTS

ALICE

The collisions at A Large Ion Collider Experiment are between heavy ions - large atoms that have had electrons ripped off.

LHC-BEAUTY

This looks at particles that include the bottom quark and for evidence of differences between matter and antimatter.

LHC-FORWARD

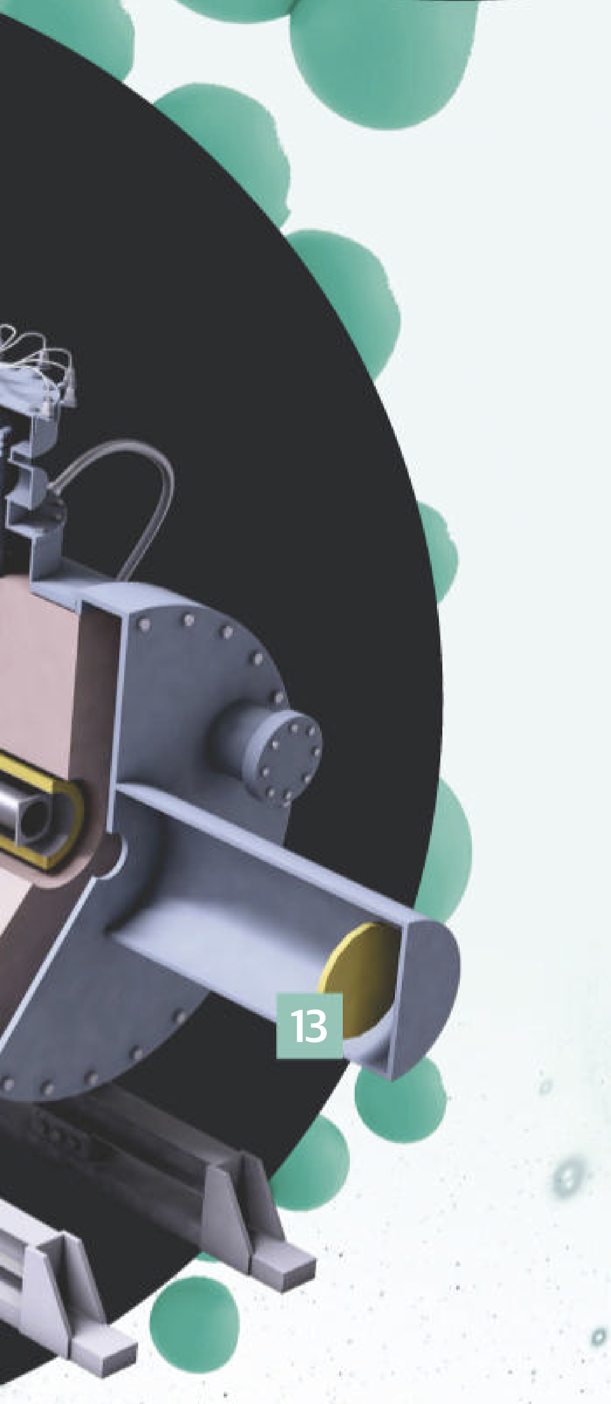
An experiment to simulate cosmic rays striking our atmosphere.

ATLAS

A Toroidal LHC Apparatus is looking for new physics by slamming protons together.

CMS

The Compact Muon Solenoid searches for and characterises the much sought after Higgs boson.



> “OUR EXPERIMENTS COULD BE A SIGNIFICANT STEP IN SOLVING THE MYSTERY OF THE MISSING ANTIMATTER IN OUR UNIVERSE”
>
> NIELS MADSEN

the way it interacts with any ordinary matter surrounding it. Like with the colliding galaxies, the resulting annihilation would create a distinctive burst of gamma rays. Inspired by the discovery, Dupourqué searched through ten years of data from Fermi, looking for the right kind of gamma-ray signal. Of the 5,787 gamma-ray sources he looked at, only 14 fit the bill. Dupourqué says this means there are no more than 14 antistars within a 32,600 light year radius of Earth. “To be clear, they are probably not antistars,” he says. The gamma rays could also be coming from the active centres of distant galaxies or from rapidly rotating dead stars called pulsars. Future searches could rule out antistars by looking for these less exotic objects.

Still, Dupourqué’s work is important because it places an upper limit on the possible local antistar population. A maximum of 1 in 400,000 stars in our local neighbourhood could be antistars. Scaling that up to the whole Milky Way, there are no more than a million antistars scattered among its estimated 400 billion ordinary stars. It adds to the idea that antistars, and by inference antigalaxies, are very rare, and the universe really does have a strong preference for matter over antimatter.

For antigalaxies to exist, antistars would have to clump together into larger structures. One such structure is a globular cluster, a dense blob of old stars that typically orbits around galaxies. There are about 150 swirling around our home galaxy, the Milky Way. A team led by Maxim Khlopov from the Southern Federal University in Russia wondered what would happen if one of those globular clusters, Messier 4, was made entirely of antistars. In a paper released in November 2020, the team discusses three different ways antimatter from antistars in M4 could reach Earth.

The first, as we’ve seen, is through a solar wind. Other space weather events such as solar flares and coronal mass ejections could also fire antiparticles across the void. Yet to penetrate the magnetic field of the Milky Way, enter the galaxy and reach our planet, the antiparticles would likely need even more energy than those two processes can provide. The team concluded that supernovae explosions as the antistars reached the end of their lives are the most likely culprit. It’s possible that this is the source of the antihelium seen by AMS-02.

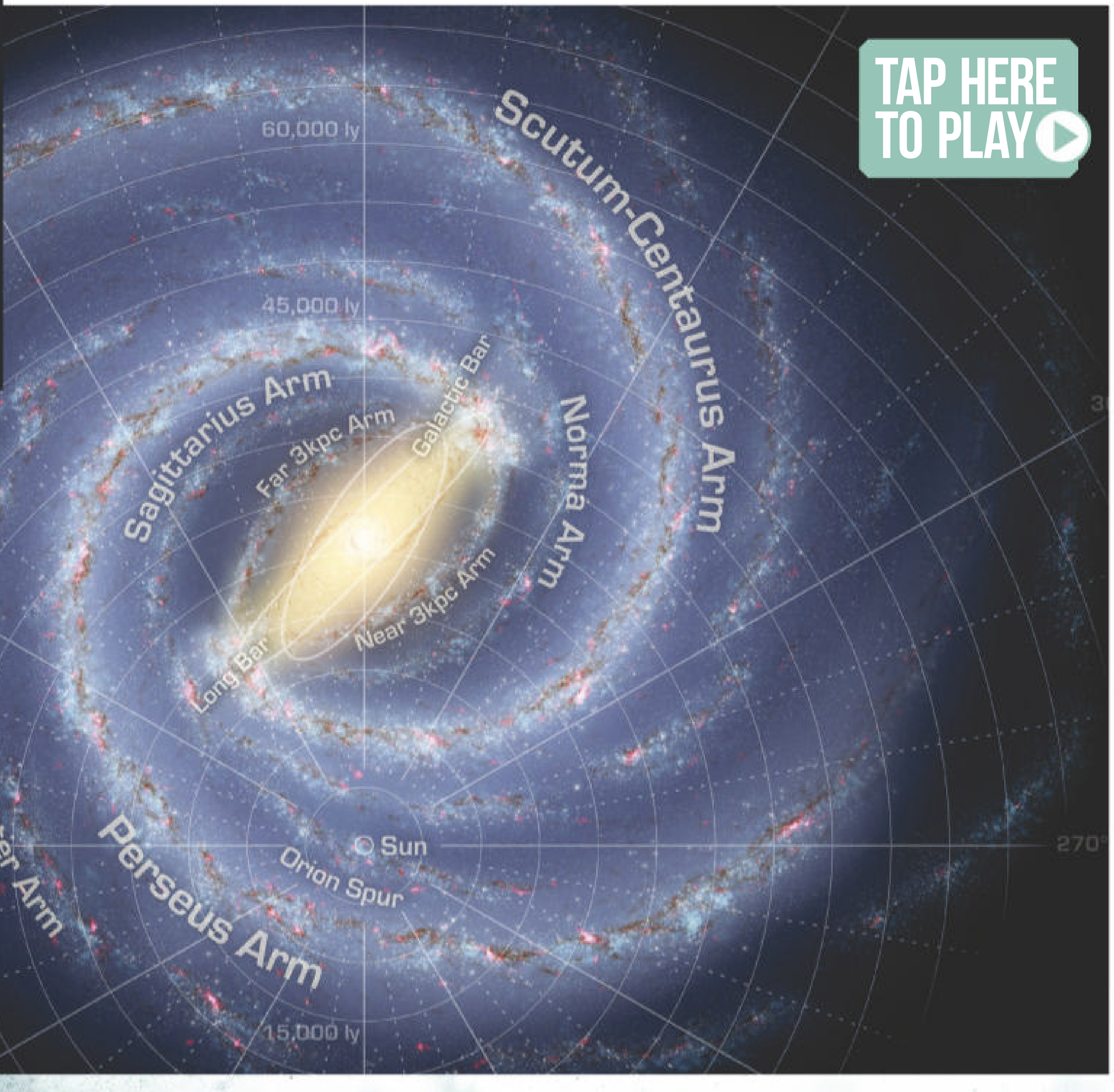
The universe keeps on dropping us tantalising clues, teasing us with strings to pull at in order to unravel one of the greatest mysteries in the cosmos. Finding out why nature prefers matter over antimatter, or whether there are vast reservoirs of antimatter huddled in distant galaxies won’t just improve our theories of physics, it’ll also tell us why we’re here to ask these questions in the first place.

Colin Stuart

Science and technology journalist

Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.

© Getty



© NASA/JPL-Caltech

Above: An experiment aboard the International Space Station may have detected eight particles of antihelium

Right: A maximum of 1 in a million stars in the Milky Way are antistars

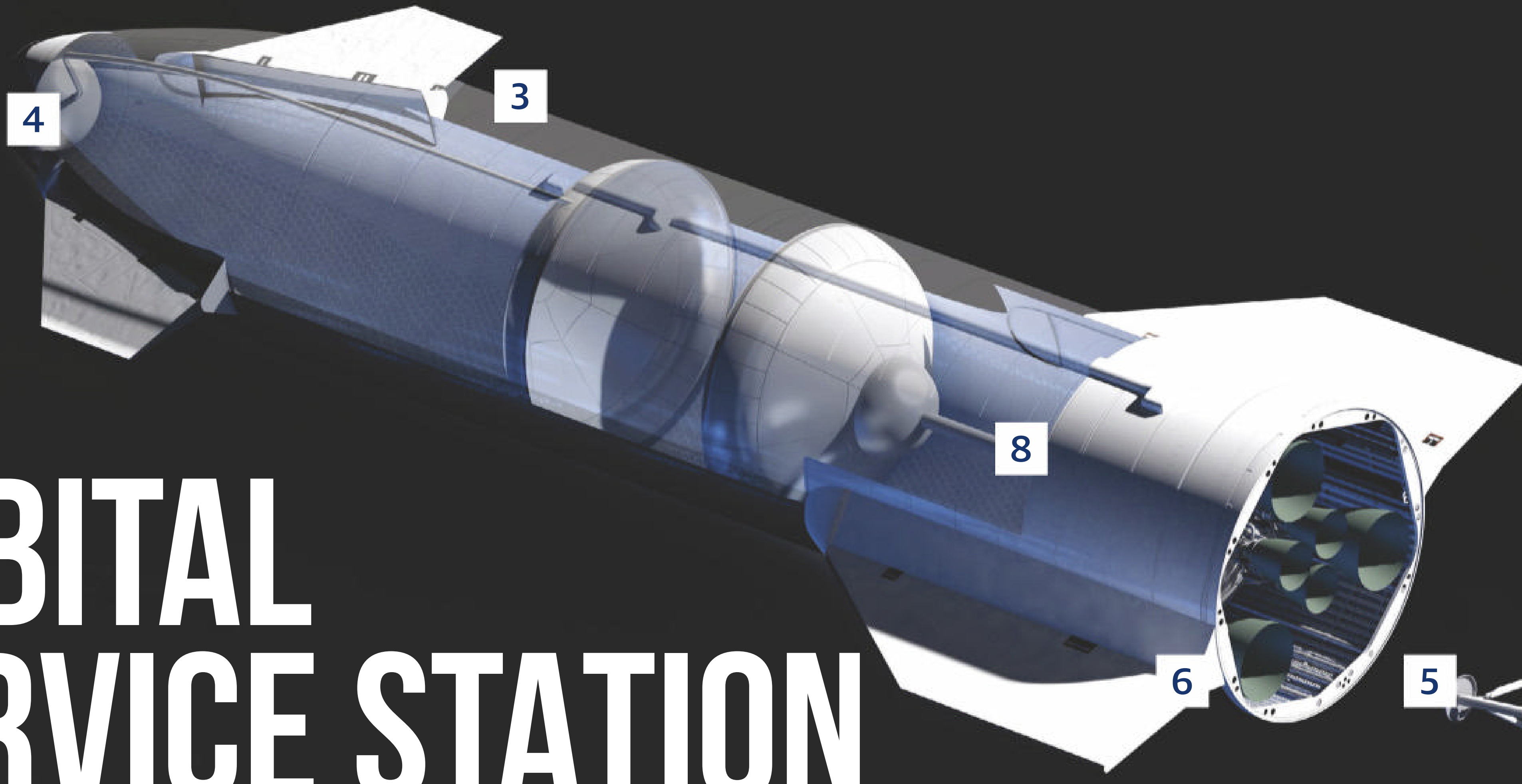
Don’t miss out on your favourite TV magazine!

BBC itv 4 5 NETFLIX prime NOW TV sky Disney+ Virgin media BBC iPlayer
Britain’s best-loved TV magazine
TV Times
Our Stri
stori
Maisie, Caroline and Rany
their all and having
NEW
His Dark Materials
The dangers that await as the drama returns...
NE
Britain’s Great Es
‘I did yoga with alp and fell in love w a horse’
sky Virgin media BEST FOR SKY & VIRGIN
MORE CHANNELS THAN ANY OTHER TV MAG!
TV&Satellite week
PLUS 5-PAGE WEEKLY GUIDE
NETFLIX prime BBC iPlayer Disney+ and more...
NEW STRICTLY It’s the launch show!
NEW ROADKILL
Hugh Laurie plays a power-hungry politician with secrets to hide
THRILLER STARTS SUNDAY ON BBC1 HD
NEW DRAMA
NEW DRAMA
LIVE FOOTBALL

On sale every Tuesday

Also available as a print or digital subscription from

www.magazinesdirect.com



ORBITAL SERVICE STATION

If rockets could be refuelled in space, it could open up interplanetary travel

Following SpaceX's first successful landing of its Starship test vehicle and the award of a NASA contract for a lunar lander based on Starship, it's looking increasingly likely that a Starship will reach orbit in 2021. When launched on its booster stage 'Super Heavy', it will become the largest launch vehicle yet, capable of placing up to 150 tonnes into orbit. But once it has done that it will have exhausted its propellants, and the driving purpose of Starship, and indeed SpaceX itself, is to provide cost-effective transport to Mars.

The first challenge was to dramatically reduce the cost of reaching space, and SpaceX set about this by developing reusable rockets – initially the Falcon 9, and now Starship. As Musk has commented, if a jet airliner was used for a single transatlantic flight before being thrown away, flights would be impractically expensive. Recovering the expensive stages and using them again was the key to getting into space cheaply enough to ship a lot of cargo and passengers to Mars. Starship will make that cheaper still, but the next challenge is to refill craft in space so they can actually go somewhere else.

Previously giant rockets, like the Saturn V and the N1, were built that way because the missions they supported were taking everything with them. Now SpaceX plans to use the cost-effective launch capability provided by Starship to refuel other Starships headed for the Moon and Mars. But just like spin gravity, orbital refuelling has been long discussed, but never done.

Typical rocket propellants are cryogenic, liquified gases, like liquid oxygen at -186 degrees Celsius (-302 degrees Fahrenheit) and liquid methane at -161 degrees Celsius (-258 degrees Fahrenheit), which are challenging enough to handle on Earth. In orbit spacecraft are exposed to extremes of temperature, and without gravity propellants will float around their tanks in blobs.

To help pioneer this capability, NASA has just given $370 (£261) million to 14 companies working on a range of orbital propellant-transfer technologies. This includes a $53.2 (£38.2) million contract to SpaceX to demonstrate full-scale pumping of liquid oxygen in zero gravity inside a Starship test vehicle. It's likely that this first test will involve pumping liquid oxygen from Starship's main tank into the small 'header tank' used to run the engines for landing. But to do this Starship will have to accelerate slightly using its manoeuvring thrusters to create a mild gravity effect and settle the liquid oxygen against one end of the tank.

Once fully operational, SpaceX plans to launch up to ten dedicated tanker Starships to refill a single crew transport Starship for trips beyond Earth. This is part of the reason launch has to be cheap. One at a time, these simplified, uncrewed tankers would dock tail to tail with the Starship and prepare it for its long journey. Orbital refuelling is one of many seemingly simple steps that must be solved on the way to Mars, which will hopefully be proven in 2021. For the Moon, Starship can carry all it needs for landing, launch and return to Earth, but when it comes to Mars fuel will be produced from the Martian atmosphere and ice, which is why SpaceX picked those propellants in the first place.

1 LOW-EARTH ORBIT

The initial launch process will put the Starship into low-Earth orbit, with the first-stage booster 'Super Heavy' landing for reuse.

2 INTERPLANETARY STARSHIP

The aim of Starship is to provide cost-effective transport to Mars, carrying as many as 100 passengers.

3 STARTANKER

A simplified Starship Tanker will carry propellants as a payload to orbit, retaining only enough for landing.

4 HEADER TANKS

Starship has small sub tanks, called header tanks, which keep propellant for landing. The demonstration project will pump liquid oxygen from the main tank to the header tank while in orbit.

5 TAIL-TO-TAIL DOCKING

All built to a standardised pattern, Starships will be able to dock together to exchange propellant.

6 MANOEUVRING THRUSTERS

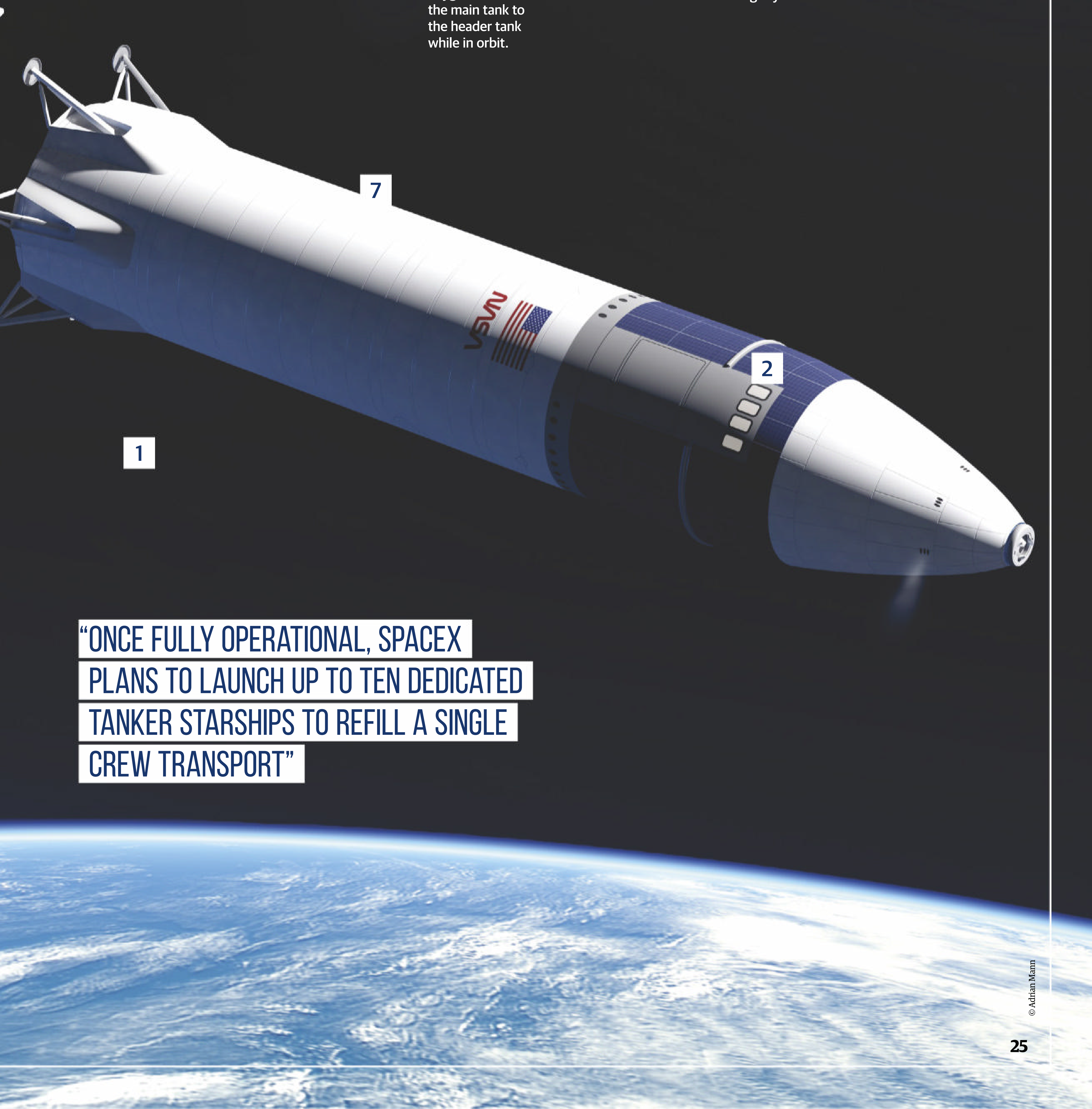
Propellants need settling against the pipes at the 'bottom' of the tank; Starships will accomplish this by firing their thrusters to accelerate slightly.

7 LUNAR STARSHIP

SpaceX's lunar-landing Starship would cycle between the Moon's surface and low-Earth orbit to be refuelled by the tankers.

8 LOX AND METHANE

Liquid oxygen and methane store at similar temperatures and burn cleanly, giving advantages over liquid oxygen and hydrogen or kerosene.



"ONCE FULLY OPERATIONAL, SPACEX PLANS TO LAUNCH UP TO TEN DEDICATED TANKER STARSHIPS TO REFILL A SINGLE CREW TRANSPORT"

© Adrian Mann

INTERVIEW

BIO

Dr Meredith Rawls

Rawls is a stellar astronomer and software developer working as a research scientist with the Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) group at the University of Washington. As a software developer, Rawls is involved in developing algorithms that can identify objects in telescope data that have changed and characterise them accordingly. Her work also entails researching how low-Earth orbit satellites affect astronomy and what satellite operators can do to reduce their impact on the night sky.

© Robert Markowitz/NASA

DR MEREDITH RAWLS

SATELLITES VS ASTRONOMY

Rawls speaks to **All About Space** about the impact of low-Earth orbit satellites on ground-based astronomy and how our experience of the night sky is going to change

Interviewed by Daisy Dobrijevic

How do low-Earth orbit satellites pose a problem for ground-based astronomy?

The main thing is that there are so many of them that are currently being launched, and are planned to be launched, and they reflect sunlight, so they can be really bright. The brightness actually surprised some of the satellite operators - they hadn't anticipated how bright their satellites were actually going to be. Astronomers were used to sometimes seeing satellites, but now it's an order of magnitude more, and they're going to be showing up very commonly in observations from ground-based telescopes.

We have had low-Earth orbit satellites for many years. Have they always been a problem?

When I was at grad school, as an observational astronomer you learn that there's a lot of stuff you're going to have to deal with. To take a picture of some stars or galaxies there's a bunch of Earth atmosphere effects. There might be light pollution, so there might be background levels of effects that you have to subtract from your observations - lots of steps to take just to try and get an image that's representative of what's actually going on in space. Until recently, to me satellites were just another one of those things that occasionally would happen. It wasn't something that was at the forefront of my mind until relatively recently.

Are all aspects of astronomy affected?

I tend to be very biased towards ground-based optical astronomy because that's our human experience with the night sky, and they're the main kinds of observations that I was trained in as a student. But radio astronomy is maybe going to be even more severely impacted than optical astronomy. It's complicated.

Radio astronomers have been competing for years for a frequency spectrum. They have these national and international relations about who gets what frequencies on the radio spectrum - your mobile phone service, your WiFi, any gadget that transmits has to have approval. Radio astronomers have fought long and hard to make their presence known and say: "We need this chunk of the spectrum because that's where hydrogen emits. We can't change that." In the US they go to lobbying meetings to make their voices heard, so there is already a presence of radio astronomers in some of these regulatory spaces.

The issue with growing numbers of low-Earth orbit satellite constellations is that one of the main goals they have is to send down high amounts of data for internet access, so they'll be constantly beaming loud radio signals down to Earth so people can get their internet connection. This is potentially going to cover a large amount of ground.

There are some things that they could do to try and lower the effects on radio astronomy, for example turning off their transmitters when they are over radio telescopes. But the reality is that if you have located a set of frequencies that you are going to use, physically these waves spill over the edges. You cannot have a sharp cut off… it's just not how waves work.

Right: A long-exposure image showing one of SpaceX's launches

© SpaceX

Even with the best intended regulations controlling what frequencies are being used by satellite companies, it's going to have some pretty serious effects on radio astronomy.

You are working on the Legacy Survey of Space and Time (LSST). What will this survey study?
The Vera C. Rubin Observatory is the site in Chile where we are building this giant telescope. It's going to survey the entire night sky of the Southern Hemisphere, so every few days there will be a new image of pretty much every chunk of sky. After ten years - which is how long the survey is going to last - we will have a high-resolution full-colour movie of the night sky. We will be able to see lots of things that are changing, maybe discover new science that we didn't know about and also see really faint structures that we haven't been able to see before.

It's everything from asteroid discovery and Solar System science to figuring out the fate of the universe. It really encompasses all areas of astronomy, which is why it is super cool.

The data is going to be published and made available to all astronomers in the US and Chile. It will be immediately made public, and then a subset of it will be going public globally. Then it will be made fully public two years after the fact, so we really want to enable science on a large scale.

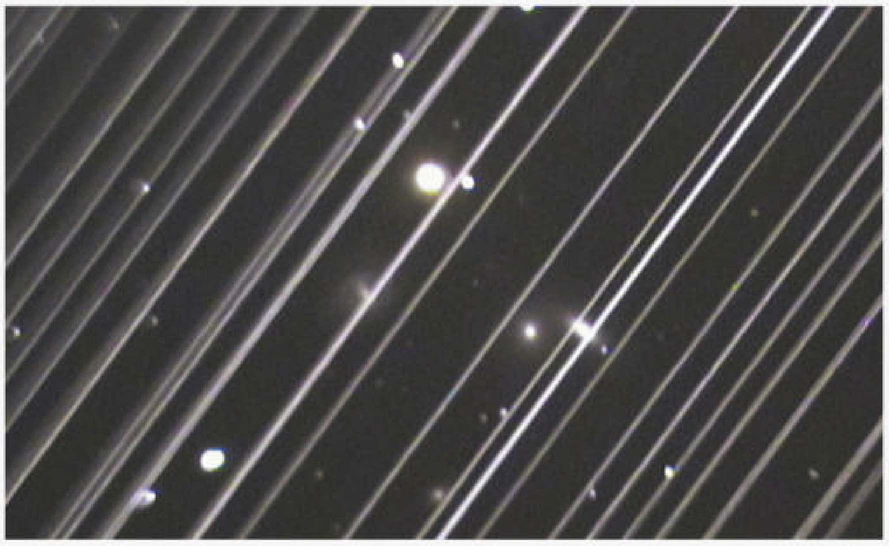
How will the planned ten-year survey at the Vera C. Rubin Observatory be affected by low-Earth orbit satellites?
It turns out that the aspects of the Vera Rubin Observatory that make it so amazing as a discovery engine for the unknown are the same characteristics that make it vulnerable to low-Earth orbit satellites that are bright and everywhere. It's hard to predict exactly what the effects are going to be, but I think they're going to be significant, especially as more and more satellites go up.

How can the interference from these satellites be reduced?
Astronomers have been in dialogue with some folks from different satellite operator companies, and generally when we have been in contact with these operators they have been receptive to not wanting to ruin the night sky, but they do also want to deliver their product and make money.

If it's not too technically difficult to do some small to medium things to make it a little easier for astronomy to not be totally messed up they've been willing to do it, which has been really nice. I don't think that is going to necessarily fix it, but it is going to somewhat mitigate it. For example, we have worked with SpaceX where we were coming up with different darkening mitigations, and we were observing the results and reporting back on whether they made a difference or not.

The first generation of that was called DarkSat, when SpaceX painted a whole satellite in dark, black paint. It did make it a little darker, but the issue from their end was that it made the satellite too hot, and it didn't function well. The next thing SpaceX tried was installing a little visor flap that would shield the reflective parts so they wouldn't reflect as much sunlight, but there were not as many observations of VisorSat because of the pandemic, as many of the ground-based observatories were closed. Some of the data suggested that the visors were able to reduce the brightness of the satellites by an order of magnitude, which is good, but not good enough.

There are ongoing discussions about other potential darkening mitigation options, because these satellite companies really do move fast. One thing that has really struck me as I have become


© Lowell Observatory

© SpaceX

© SpaceX

Far left (clockwise): An image taken of the NGC 5353/4 galaxy group at the Lowell Observatory in Arizona shows trails of reflected light from recently launched Starlink satellites as they passed through the telescope's field of view

An arc of light from a SpaceX launch

A fleet of SpaceX Starlink internet satellites prior to their release into orbit familiar with this whole situation is how fast satellite companies move compared to astronomy and science, which tends to be on a much longer timescale to get a project up and running. But then regulation moves on even longer timescales, so they are really mismatched.

If low-Earth orbit satellites are problematic, should the companies just place the satellites higher up?
Actually that would be worse. It's a little complicated because you could think that maybe a lower orbit satellite would be brighter because it is closer, which is true, but the trick is that it moves faster in a lower orbit because it has to not fall out of the sky. That means that when you are taking a picture it will move out of the way faster and the pixels won't linger long enough to make as bright of a streak in the image, which is better.

I was personally disappointed that OneWeb decided to keep its satellites at a higher altitude, whereas SpaceX has been more willing to keep its satellites at lower altitudes. Though space debris will become an even bigger problem at these lower altitudes as the lower the orbit, the more crowded it gets.

Could these satellites be influencing not only ground-based astronomy, but also general enjoyment of the night sky?
These low-Earth orbit satellites are fundamentally changing the night sky. My kids are going to have a very different experience of what it means to go to a dark site and stargaze. Even if you are far away from a city and there's not much traditional light pollution, you're going to find a whole bunch of moving things in the sky. If satellite companies manage to get the brightness below seventh magnitude, or at least close, they might not be super bright, and you won't necessarily be able to see the satellites unless they are glinting at certain times of the night. But even in a best case scenario where all of the satellite operators agree to reduce the brightness, you're still ruining astrophotographers' views of the night sky.

And even if they can manage to make them seventh magnitude or fainter when they are at their main orbital altitude, they still have to launch them. When they are launched, the satellites have to spend a little bit of time at a really low altitude - which is when they're at their brightest - before they manoeuvre up into a higher orbit. At the end of their lifetime, which is usually about five years, they're also going to be brighter when they are on their way back down. You might say that's only a month in a five-year lifetime, but it's constant. They're going to be replenishing the satellites that are up there. They're always going to be launching some and deorbiting others, and there are a number of companies doing this at once.

Right: The Vera C. Rubin Observatory at twilight

© Rubin Obs

> IT'S REALLY JUST A BUNCH OF COMPANIES WHO ARE DECIDING WHAT THE FUTURE OF THE NIGHT SKY IS GOING TO BE FOR EVERYONE. I DON'T THINK THAT'S A GREAT WAY TO PROCEED.

Something else that I would like to stress is the bigger picture of all of this. I obviously care a lot about the science, but I do really care a lot about the impacts on the human experience of the night sky. There are a whole bunch of folks who have not been invited to any of the discussions about this - in particular indigenous folks and religious practitioners. People have all kinds of different relationships with the night sky, and I think that it's really important to seek out and listen to those folks as well, because they are not getting a say at all. It's really just a bunch of companies who are deciding what the future of the night sky is going to be for everyone. I don't think that's a great way to proceed.

Do you think these satellites could make ground-based observations impossible?
Some people ask: "Why can't you just launch all these telescopes into space and solve this problem?" But unfortunately this is not realistic for a whole bunch of reasons, funding being the main one.

Also, the kind of survey that we will be doing at the Vera Rubin Observatory - where you are trying to do a wide-field survey of the night sky - you cannot do that with a space telescope because you cannot get the hardware up there - it's that big. If anything breaks, you can't necessarily service it. When the James Webb Space Telescope launches, it's going to be so far out that it cannot be serviced, so if anything breaks, that's it. It just makes us all very nervous.

I don't think it'll be impossible, but it will be harder. We are used to dealing with a lot of interference in our data - that's not really fundamentally new - but I do think that we will miss discoveries that we basically don't know we will have missed. That's what scares me most about the scientific impact of this whole thing: that we won't know what we cannot see.

For example, maybe we'll miss a near-Earth asteroid. One of the many things that the LSST survey is going to do is aim to discover a whole bunch of near-Earth asteroids. But to do that search it has to do it at twilight, and it's during this time that there are the most illuminated satellites.

If you can't image the same asteroid three or four times, you can't measure its orbit, and you have no idea if it's going to come close to impacting Earth. The fact that we have tonnes of satellites may make it impossible to tell if there's going to be a dinosaur-level asteroid situation, so that's kind of an irony for you.

© Nicholas Forder

EVERYTHING YOU NEED TO KNOW ABOUT...

THE SOLAR SYSTEM

Join us on a tour through our current understanding of the planetary system we call home

Reported by Giles Sparrow

INTRODUCING THE SOLAR SYSTEM

Our Solar System consists of the area influenced by the Sun and, apart from occasional stray visitors from interstellar space, everything it contains. Aside from the Sun, its main components are the eight major planets, their moons and rings, a handful of worlds classified as dwarf planets and vast numbers of smaller bodies made of varying amounts of rock and ice, which are broadly termed asteroids and comets. Most of these objects orbit in a plane roughly in line with the Sun's equator and in the same direction as the Sun's rotation – anticlockwise when viewed from 'above' the plane.

The four innermost planets are mostly composed of dense rock and metal. Earth is the largest of these 'terrestrial' planets, with Venus almost the same size, Mars significantly smaller and Mercury the smallest of all. A large gap separates the orbit of Mars from that of Jupiter, the innermost gas giant and the largest planet in the entire Solar System, with a diameter of 11.2 Earths. Saturn is somewhat smaller, and outer Uranus and Neptune are near twins, both about four times the diameter of Earth.

The entire Solar System sits in the Milky Way – a vast spiral galaxy within which the Sun is just one of several hundred billion stars. At about 26,000 light years from the centre, it takes some 230 million years to complete one trip around the galaxy.

TAP HERE TO PLAY ▶

AN EVOLVING SYSTEM

Our neighbourhood hasn't always been quiet

Although today's Solar System seems stable, it represents just a snapshot in a long history of change and evolution. Asteroids and comets in planet-crossing orbits are doomed to suffer disruption of some kind on astronomical timescales, and so their supplies must continuously be replenished. In the first billion years of Solar System history, however, changes were far more dramatic. It's increasingly clear that the giant planets formed closer to the Sun – and to each other – than they are now, and a subsequent gravitational tug of war saw their orbits evolve and change. Jupiter may have first migrated even closer to the Sun, scattering vast numbers of icy objects from the outer edge of today's asteroid belt and beyond into extreme elliptical orbits to form the Oort Cloud, before reversing its track. Neptune may have started its life closer to the Sun than Uranus before their own complex gravitational dance swapped them over, pulling Uranus' axis of rotation over to its extreme 98-degree angle. Some computer models even suggest that in order to reach the current configuration of giant planets, there must once have been a fifth Neptune-sized world that was long ago ejected from the Solar System entirely, or perhaps flung into exile amid the comets of the Oort Cloud.

> "AS THE SUN BECAME HOT ENOUGH TO SHINE PROPERLY, RISING TEMPERATURES CAUSED EASILY MELTED CHEMICALS TO EVAPORATE"

TAP HERE TO PLAY

ORIGINS

Evidence from rock grains in ancient asteroids suggests the Solar System began to form about 4.57 billion years ago. Like other stars, the Sun was born from a collapsing cloud, or nebula, rich in gas and dust. As the centre of the cloud grew hotter and denser it began to spin more rapidly, while material around it flattened out into a rotating disc. Dust grains collided and stuck together in the disc, perhaps growing step by step through chance collisions until they had sufficient gravity to draw in more material from around them, or perhaps forming huge clouds of orbiting 'pebbles' that underwent sudden collapse into larger protoplanets when they became unstable.

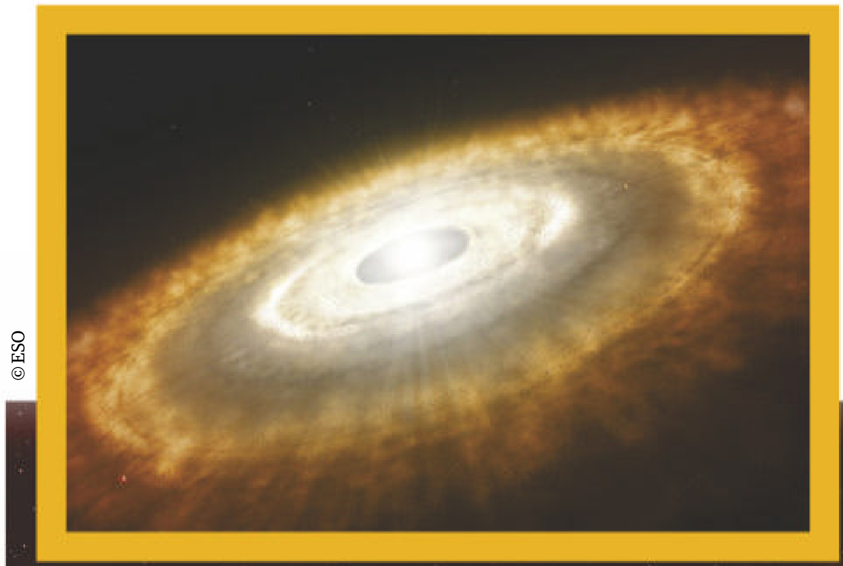
Meanwhile, as the Sun became hot enough to shine properly, rising temperatures caused easily melted chemicals to evaporate as far out as an 'ice line' in the present-day asteroid belt. Simultaneously, fiery radiation from the newborn Sun and a solar wind of ionised particles blowing out from its surface began to drive gas outwards. While the worlds of the inner Solar System had to form mostly from dry, rocky materials, those farther out incorporated substantial amounts of ice, and in the case of the largest planets were also able to keep hold of huge gaseous atmospheres thanks to their powerful gravity.

THE SUN

Our local star controls conditions across the wider Solar System. With a visible diameter of 1.39 million kilometres (860,000 miles), it accounts for some 99.8 per cent of the Solar System's entire mass and has a composition dominated by hydrogen – the lightest and simplest gas in the universe.

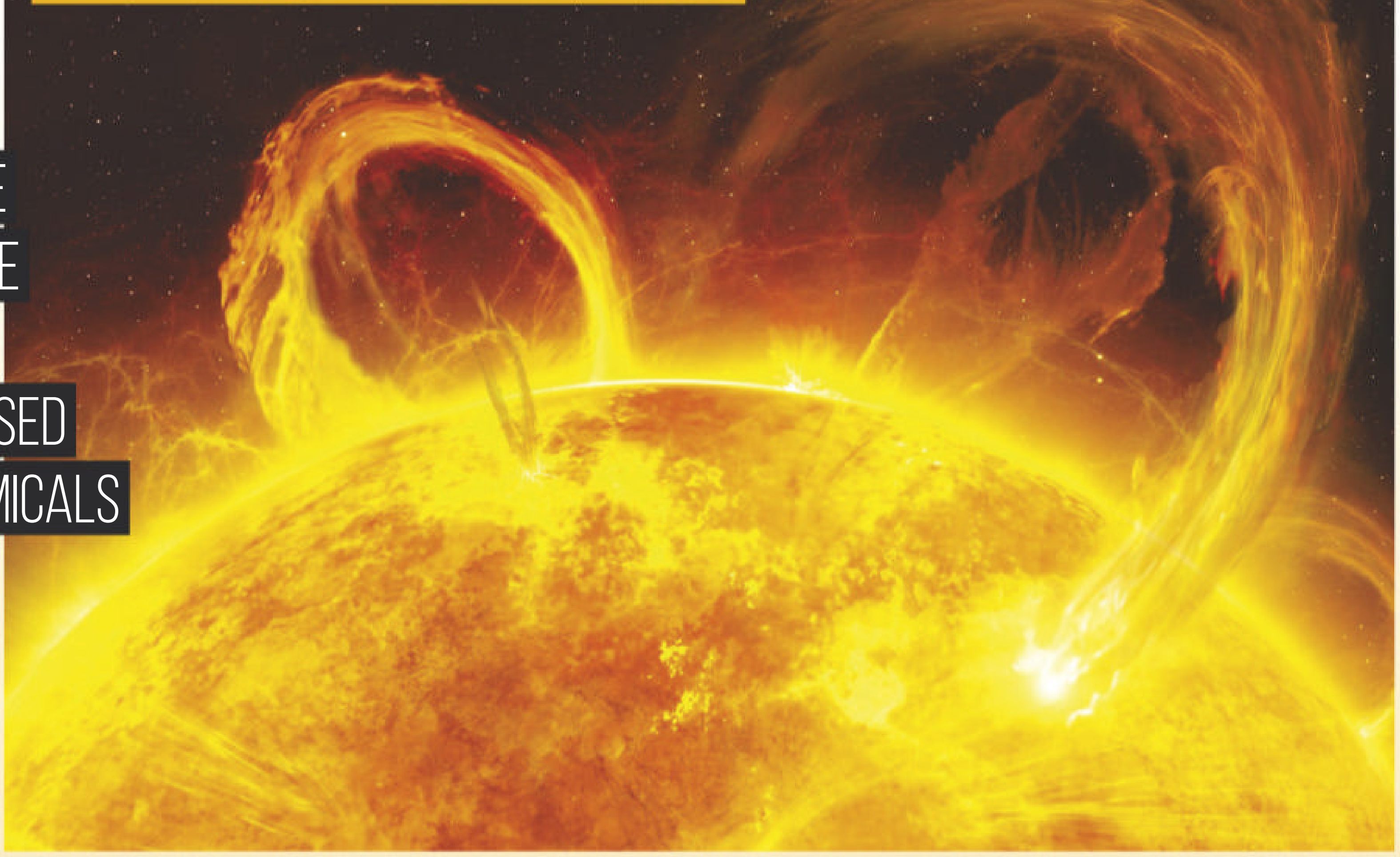
The Sun shines by nuclear fusion, a process that forces hydrogen nuclei together in the core to form nuclei of helium, the next lightest element. Energy is released in the process as photons of high-energy radiation that gradually force their way outwards through the overlying layers, losing energy as they do, and keeping the Sun's interior hot. The Sun's incandescent visible surface, or photosphere, marks the region where its gas becomes cool and sparse enough to be transparent, and visible, infrared and ultraviolet light can escape. This surface has an average temperature of around 5,500 degrees Celsius (9,932 degrees Fahrenheit), although dark sunspots, created where the Sun's tangled magnetic field bursts from its surface, can be a couple of thousand degrees cooler.

Above the photosphere, the Sun's upper layers are home to violent activity that varies, along with sunspot numbers, in an 11-year cycle. The cycle significantly affects the shape of the Sun's corona,



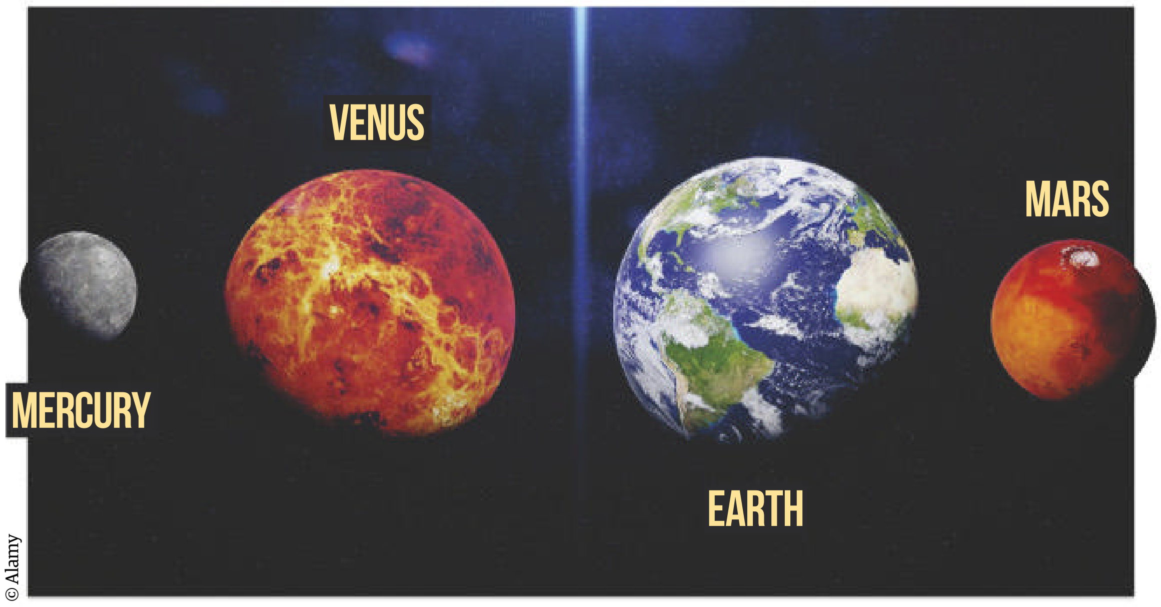
Below (top): Everything in the Solar System formed from a protoplanetary disc around the Sun

© ESO



Below: The Sun sends out ionised particles that carry through to the outer reaches of the Solar System

© Tobias Roetsch



© Alamy

Left: Our home planet is the largest of the four rocky bodies closest to the Sun

or outer atmosphere, which typically extends to several times its visible diameter before merging with the solar wind of particles blowing out across the Solar System.

ROCKY PLANETS

A variety of factors have shaped the evolution of the terrestrial planets – most importantly their size, composition and distance from the Sun. As a rule, the larger a planet is, the hotter its interior will remain, giving rise to a more complex structure and potentially a molten metallic core. Size and mass determine a planet's gravity, which along with its temperature and the presence of a protective magnetic field influence how well it can hold on to an atmosphere. These factors influence the chemicals that can exist on its surface.

It's likely that all four rocky planets were bombarded by icy objects from farther out in the Solar System during or shortly after their formation, returning water to their surfaces. Venus, Earth and Mars all once had oceans of liquid water, but Venus' was lost to a runaway greenhouse effect early in its history, leaving behind an arid, hellish landscape. The weak gravity and lack of a protective magnetic field around Mars, meanwhile, allowed much of its atmosphere and water to escape into space, cooling the surface until most of the remaining water became locked in permafrost and the polar ice caps. Venus and Mars show signs of geological activity in the relatively recent past, but this mostly takes the form of volcanism, while activity on Earth is far more complex and continuous.

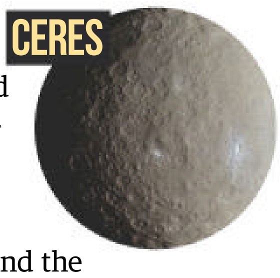
GIANTS OF GAS AND ICE

The giant planets of the outer Solar System are broadly divided into two pairs: the inner gas giants Jupiter and Saturn, dominated by huge envelopes of hydrogen, and the outer ice giants Uranus and Neptune, made of more complex chemicals such as water, methane and ammonia. All four have deep outer atmospheres that are home to complex weather systems. Despite their size these planets spin rapidly, generating high winds that wrap cloud systems into bands parallel to their equator.

Beneath the active atmospheres of Jupiter and Saturn, pressure from above forces hydrogen into a liquid state, and can even break it down into liquid metallic form, generating extremely powerful magnetic fields. The deeper layers of Uranus and Neptune, meanwhile, are composed of icy chemicals in liquid form. Slow contractions of the inner layers due to gravity, coupled with chemical reactions, generates significant heat inside three of the giants, though Uranus is a mysterious exception, helping to power their weather systems even in the cold outer Solar System.

The considerable gravity of the giants puts each one at the centre of its own substantial satellite system – all four are orbited by a mix of 'regular' moons, formed from material left in orbit as the planet itself formed, and 'irregular' objects captured during later close encounters. Each giant also has a ring system of its own, made up of particles trapped in concentric orbits. These vary wildly between the broad, icy planes of Saturn to the tenuous dust around Jupiter and the tightly defined arcs around Uranus and Neptune.

DWARF PLANETS



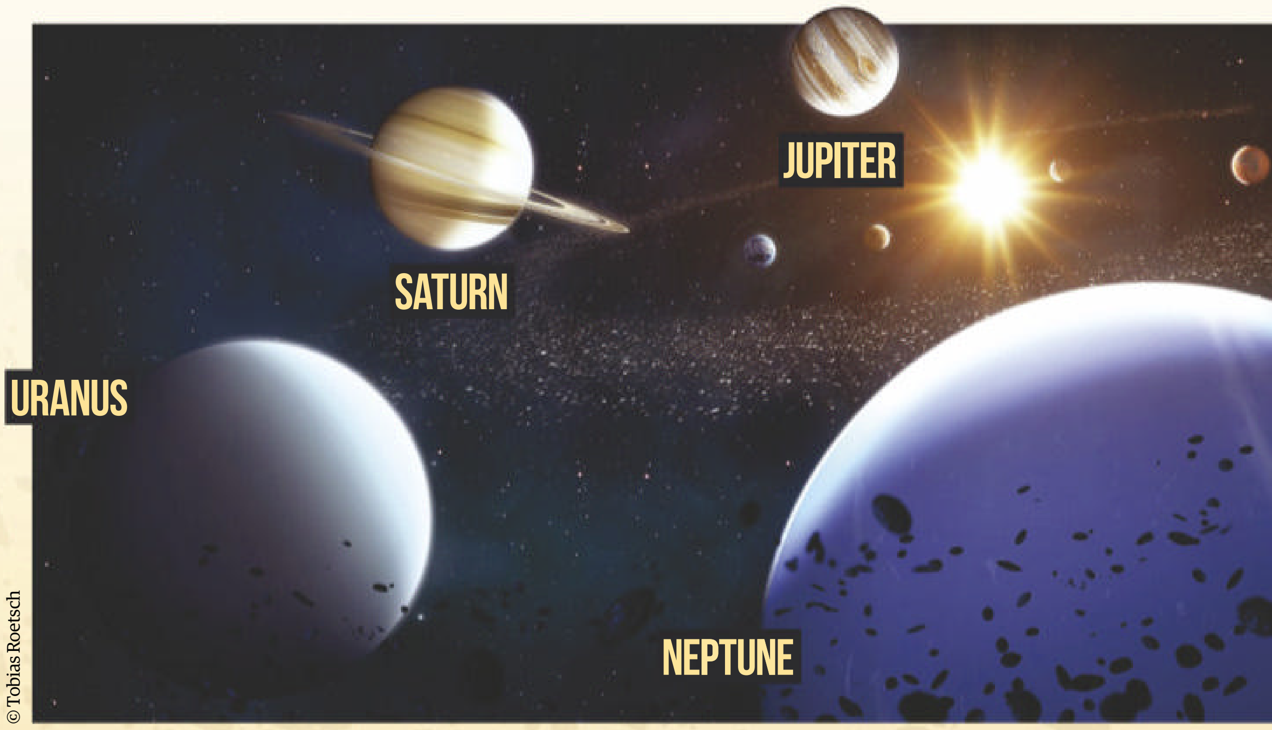
The term dwarf planet was introduced to clarify the organisation of the Solar System in 2006 – though some might say it's made matters more confusing. Dwarf planets are worlds in orbit around the Sun with sufficient gravity to pull themselves into a spherical shape, but not enough to deflect the paths of other nearby bodies and 'clear their orbits'.

The first dwarfs to be discovered were Ceres in 1801 and Pluto in 1930. Both were originally treated as new major planets, despite their small size, but Ceres was swiftly reclassified as an asteroid once more of its neighbours in the main asteroid belt were discovered. Pluto's status became doubtful in the 1990s as more small bodies in similar orbits were found in the Kuiper Belt, but matters came to a head with the discovery of Eris, another 'trans-Neptunian object' of similar size, in 2003.

Faced with a potentially ballooning list of 'major' planets, astronomers opted to introduce the new category, demoting Pluto, but sweeping up Ceres into the bargain. Because dwarf planets are classified in part by their shape, and this is still uncertain for some distant worlds, there are still fierce debates about which objects qualify. The International Astronomical Union currently recognises just five: Ceres, Pluto, Haumea, Makemake and Eris.

Source: Wikipedia Commons © Justin Cowart

Right: Beyond the asteroid belt, the planets are gaseous and gigantic in comparison to Earth



© Tobias Roetsch

LIFE IN THE SOLAR SYSTEM

Could there be life outside of Earth?

Earth's abundant life is due to its unique position in the Solar System near the inner edge of our Solar System's 'Goldilocks zone', where temperatures are neither too hot nor too cold, but 'just right' for liquid water to survive on a planet's surface. Water is widely seen as a key requirement for life because it's the most abundant and effective 'solvent' that we know of – a chemical within which other molecules can dissolve and move around, permitting the encounters and reactions that are needed for life to evolve and survive.

Mars is the only other planet technically just within the Goldilocks zone, and its warmer, wetter history makes it an intriguing destination in the search for past or present life, but there are also surprising possibilities farther from the Sun.

Several large satellites and dwarf planets seem to have liquid-water layers deep in their interiors, while tidal forces raised by Jupiter and Saturn on their icy moons Europa and Enceladus pummel and heat their interiors so much that they have substantial liquid-water oceans just below the surface. Fed with chemical nutrients by undersea volcanoes, these two worlds are seen as the Solar System's most likely spots for alien life to exist.

"THESE ICY WANDERERS SPEND MOST OF THEIR LIVES IN A DEEP-FROZEN STATE"

Below: 'Oumuamua was identified as an interstellar interloper passing through our Solar System

TAP HERE TO PLAY

© ESO

ROCKY DEBRIS

Although the formation of the Solar System left plenty of rock and dust scattered across the inner Solar System, most of the smaller rocky objects that survive today are confined to the asteroid belt between Mars and Jupiter, where the giant planet's gravity and early shifts in its orbit disrupted any potential for the formation of a fifth rocky planet. Today's asteroid belt contains around 1.5 million asteroids more than one kilometre (0.6 miles) across, along with countless smaller objects.

Although they're scattered across such a vast volume of space that crossing the belt is easy, collisions and close encounters are inevitable on a longer timescale. These lead to the formation of asteroid families with similar compositions and orbits that can be traced back to a common origin. Asteroids vary in composition from 'carbonaceous' objects that have barely altered since the birth of the Solar System to bodies rich in silicate minerals or even iron – fragments of larger ancient worlds that had begun to develop an internal structure before they were smashed apart.

Collisions can also send asteroids onto elliptical orbits that cross over those of the inner planets, with some becoming potentially hazardous near-Earth objects, or NEOs. However, NEO orbits are inevitably unstable over long timescales – ending either in a collision with a major planet or more likely deflection from a close encounter – and so this supply must be steadily renewed.

Right: There are millions of tiny icy and rocky fragments floating through space

© Alamy

ICY WANDERERS

The farther out we look in the Solar System, the more volatile ices – not just water ice, but also frozen methane and other compounds – become mixed with the rocky components of solid bodies. This trend is already apparent fairly close to the Sun in the asteroid belt, but it becomes more pronounced among the moons of the giant planets, and above all in the small worlds of the Kuiper Belt beyond Neptune.

The most familiar icy objects, however, are comets. These icy wanderers spend most of their lives in a deep-frozen state, orbiting among the Kuiper Belt objects or even farther out in the Oort Cloud – a vast, spherical comet cloud that surrounds the Solar System. However, they spark into life when chance puts them on an elliptical orbit that brings them close to the Sun. As the comet's solid nucleus warms up, gases evaporating from the surface first form a vast, diffuse atmosphere, called a 'coma', and then an elongated tail that is caught up on the solar wind and dragged away from the Sun.

Comets that visit the inner Solar System may follow orbits that vary from just a few years to tens of thousands. However, each successive visit strips away some of their ice until they eventually become dark, dormant and – depending on their orbits – barely distinguishable from asteroids.

TESTING THE LIMITS

Many astronomers from across the world define the Solar System's outer limit as the boundary where the Sun ceases to be the exclusive dominant influence over nearby objects. According to this definition, the edge of the Solar System lies at the heliopause – the wall where the solar wind streaming out from the Sun comes to a halt in the face of pressure from countless other stellar winds and the 'interstellar medium' – clouds of sparse gas that lie between the stars.

This boundary lies around four times farther from the Sun than Neptune, or 120 times farther out than Earth. Four spacecraft – Pioneers 10 and 11 and Voyagers 1 and 2 – have crossed it so far, and the two Voyagers continue to send back data about conditions on the other side.

Despite the widespread adoption of the heliopause as the formal 'edge' of the Solar System, there are many objects in the space beyond it that still orbit the Sun. Most of these lie within either the scattered disc, a broad outer extension of the Kuiper Belt, or the Oort Cloud. According to the most generous definition, the Solar System extends to the edge of the Oort Cloud, roughly a light year from the Sun.

THE EIGHT MAJOR PLANETS

SCAN HERE FOR AR MODELS

MERCURY

Diameter: 4,879 kilometres (3,032 miles)

Mass: 0.055 Earths

Distance from the Sun: 46 to 69.8 million kilometres (28.6 to 43.4 million miles)

Orbital period: 88 days

Rotation period: 58.65 days

Axial tilt: 0.03 degrees

Satellites: Zero

VENUS

Diameter: 12,104 kilometres (7,521 miles)

Mass: 0.815 Earths

Distance from the Sun: 107.5 to 108.9 million kilometres (66.8 to 67.7 million miles)

Orbital period: 224.7 days

Rotation period: 243.02 days

Axial tilt: 177.36 degrees

Satellites: Zero

EARTH

Diameter: 12,742 kilometres (7,918 miles)

Mass: 5.97 billion trillion tonnes

Distance from the Sun: 147.1 to 152.1 million kilometres (91.4 to 94.5 million miles)

Orbital period: 365.256 days

Rotation period: 23 hours and 56 minutes

Axial tilt: 23.44 degrees

Satellites: One

MARS

Diameter: 6,779 kilometres (4,212 miles)

Mass: 0.107 Earths

Distance from the Sun: 206.7 to 249.2 million kilometres (128.4 to 154.8 million miles)

Orbital period: 686.98 days

Rotation period: 24 hours and 37 minutes

Axial tilt: 25.19 degrees

Satellites: Two

JUPITER

Diameter: 139,822 kilometres (86,881 miles)

Mass: 317.8 Earths

Distance from the Sun: 740.5 to 816.6 million kilometres (460 to 506.4 million miles)

Orbital period: 11.86 years

Rotation period: 9 hours and 55 minutes

Axial tilt: 3.13 degrees

Known satellites: 79

SATURN

Diameter: 116,464 kilometres (72,367 miles)

Mass: 95.2 Earths

Distance from the Sun: 1.35 to 1.51 billion kilometres (838 to 938 million miles)

Orbital period: 29.46 years

Rotation period: 10 hours and 34 minutes

Axial tilt: 26.73 degrees

Known satellites: 82

URANUS

Diameter: 50,724 kilometres (31,518 miles)

Mass: 14.5 Earths

Distance from the Sun: 2.74 to 3.01 billion kilometres (1.7 to 1.87 billion miles)

Orbital period: 84.02 years

Rotation period: 17 hours and 14 minutes

Axial tilt: 97.77 degrees

Known satellites: 27

NEPTUNE

Diameter: 49,244 kilometres (30,598 miles)

Mass: 17.1 Earths

Distance from the Sun: 4.44 to 4.54 billion kilometres (2.76 to 2.82 billion miles)

Orbital period: 164.8 years

Rotation period: 16 hours and 7 minutes

Axial tilt: 28.32 degrees

Known satellites: 14

SUN

Diameter of photosphere: 1.39 million kilometres (863,706 miles)

Mass: Around 330,000 Earths

Rotation period: 25 days at equator, 34.4 days at the poles

© Getty

SUBSCRIBE TODAY AND

GET THIS BOOKAZINE BUNDLE

ALL ABOUT HISTORY
GREEK MYTHOLOG
EXPLORE THE RITES AND RITUALS OF THE A
Meet the gods & goddesses of Mount Olympus
NEW
DISCOVER HOW HUMANITY REACHED BEYOND EARTH
SPACE EXPLORATION
MARS EVERYTHING YOU NEED TO KNOW ABOUT THE RED PLANET
FROM THE MAKERS OF SPACE
RTH
COVERED
UGH THE INCREDIBLE WORLD WE LIVE IN

LIMITED TIME OFFER!

All About Space | Subscription offer

DO EXOPLANETS SHRINK WITH AGE?
3 FREE eBOOKS
All About Space
ALL-NEW AR EXPERIENCE INSIDE
ASTRONOMY VERSUS SATELLITES
ORBITAL SERVICE STATION
YOUR NIGHT SKY GUIDE
UNIVERSE'S WOBBLING PARTICLE
SUBSCRIBER EDITION
ANTIMATTER GALAXIES
HAS THE IMPOSSIBLE EXISTENCE OF THESE OBJECTS JUST BECOME POSSIBLE?

NEW!

Reasons to subscribe…

- You'll never miss an issue!
- It's delivered direct to your door
- Brilliant value – great savings on the cover price
- Special subscriber covers

Subscribe now

www.magazinesdirect.com/aas/bundle21

or call 0330 333 1113 and quote BT16

£10.65 every three months

13 issues of **All About Space** in print over 12 months

SAVE 37%

£11.90 every three months

13 issues of **All About Space** in print and digital over 12 months

SAVE 60%

£7.15 every three months

13 issues of **All About Space** in digital

Bundle not included with digital

SAVE 44%

*Terms and conditions: Offer closes 31 August 2021. Offer open to new UK subscribers only. Pricing is guaranteed for the first 12 months and we will notify you in advance of any price changes. Please allow up to six weeks for delivery of your first subscription issue, or up to eight weeks overseas. Your gift will be delivered separately within 60 days after your first payment has cleared. Gifts only available to subscribers on the UK mainland. Gift not available with a digital subscription. The full subscription rate is for 12 months (13 issues) and includes postage and packaging. If the magazine ordered changes frequency per annum, we will honour the number of issues paid for, not the term of the subscription. For full terms and conditions, visit **www.magazinesdirect.com/terms**. For enquiries please call: +44 (0) 330 333 1113. Lines are open Monday to Friday 9am to 5pm UK Time or e-mail: **help@magazinesdirect.com**. Calls to 0330 numbers will be charged at no more than a national landline call, and may be included in your phone provider's call bundle.

Félicette

THE INSIDE STORY OF A SPACE CAT

© Getty; Public Domain

WHAT HAPPENED WHEN A FELINE WAS BLASTED OFF INTO SPACE?

Reported by Stuart Atkinson

Everyone knows the story of Laika, the first animal to orbit Earth. Photos of her feature in every book written about space, and although some people are still unaware of the awful truth of how she died in orbit at the end of her flight, almost everyone knows her name and what she did. However, the same can't be said of Félicette, the first – and so far only – cat to fly in space.

Why is Félicette forgotten when Laika is so loved? Perhaps because she flew aboard a small French rocket, not one of the powerful boosters used by the competing Superpowers. Maybe it's because her flight lasted 15 minutes, only carrying her to the edge of space on a suborbital 'hop'?

Félicette was one of a group of 14 cats, all female, 'acquired' by French space scientists. Having seen the successful animal flights of the US and Russia, France – which had ambitions to launch its own astronauts – decided to stage a series of missions of their own, but using cats instead of dogs or monkeys.

Before they could begin their training the cats – which were given numbers instead of names to prevent the scientists from becoming attached to them – were fitted with electrodes to enable the scientists to study and record their brain activity and connect them to monitoring equipment. If that sounds horrendous, it is, and one photo taken during the cats' training really does show the cold contrast between how human and animal astronauts were treated.

On 9 April 1959, the US test pilots and naval aviators who had passed their gruelling and invasive training to qualify to become astronauts were revealed to the world during a high-profile press conference. They sat in a line behind a long desk, all dressed in sharp suits and ties, laughing and joking with the press. Swapping banter with each other, the Mercury astronauts were all clearly happy to be there.

The few images we have of the 'space cats' show that, unlike Alan Shepard and John Glenn, they were clearly not happy to be there. Laika was photographed standing up, tail wagging and ears pricked, but all we can see of the space cats are their heads sticking out of the tops of small white boxes, lined up on a shelf like ornaments. It's obvious they can't move inside them, and anyone who knows how restless cats can get if held still for even a few moments can appreciate how scared and utterly miserable they must have been.

To make matters worse, the photo shows the cats have what appear to be large LEGO bricks sticking out of their heads. These are actually the packages of electrodes, surgically implanted into their brains to monitor their neurological activity during their flight. They are ugly things, and many believe that they are the reason why Félicette's story is known by so few people: media outlets were clearly reluctant to use the cruel photos.

Look closely at the group photos and there on the end of the line is C 341, a small black-and-white tuxedo cat, staring out from her box with angry, narrowed eyes. Two months later the world would know her as Félicette.

After two months of training, 6 out of the 13 remaining cats were chosen to go through to the next stage of the space-age auditions they had been entered into. C 341 was one of them. Meanwhile, the rocket was being prepared.

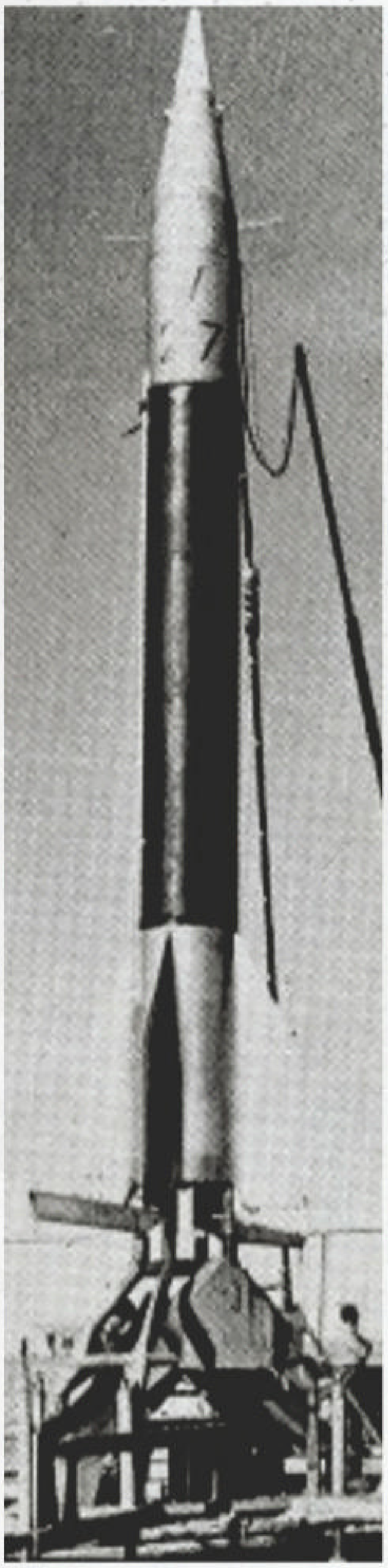
Laika had been carried into space by a 30-metre (98.5-foot) Sputnik R7 rocket, roughly the same height as the Vostok that would carry Yuri Gagarin into space four years later. The sleek Redstone rocket that carried Shepard into space inside his Mercury capsule soon after was slightly smaller at 25 metres (82 feet), but it didn't have enough power to put him into orbit.

© Getty

> "SHE FLEW ABOARD A SMALL FRENCH ROCKET, NOT ONE OF THE POWERFUL BOOSTERS USED BY THE COMPETING SUPERPOWERS"

THE FLIGHT PLAN

Félicette's flight plan was simple. The rocket would blast off, then after jettisoning its support struts and an engine burn of 42 seconds it would reach a maximum altitude of 152 kilometres (94 miles) before being pulled back down to Earth again by gravity. After re-entry the capsule would deploy parachutes to break its fall, landing around 15 minutes after it took off to be retrieved by a ground team.


© Alamy

TRAINING A FELINE

The cats' training was remarkably similar to the training their human counterparts went through. They were put into small containers and constrained for long periods to test how badly they were affected by being confined. They were placed in soundproof boxes and forced to endure simulations of the noises they would experience during blastoff – the roar of the rocket engines and the clanking of the launch. They were also put into a centrifuge and spun around to simulate the g-force of liftoff and re-entry. For C 341 and her fellow candidates, the phrase 'not enough room to swing a cat' was not applicable.

In contrast, with its tail fins and sharp, pointy nose, the Véronique AGI rocket chosen to carry the first space cat beyond Earth looked more like a Bond villain's missile or a child's drawing of a rocket. Indeed, compared to the mighty, white Saturn V, which would eventually take astronauts to the Moon, the Véronique looked like – and was – little more than a firework. But although it looked very basic, it had some very clever technology incorporated into it. For example, the rocket did not need a conventional launch tower to blast off from: four long, narrow horizontal fins, or struts, supported its weight on the launch pad, like the splayed legs of a telescope tripod.

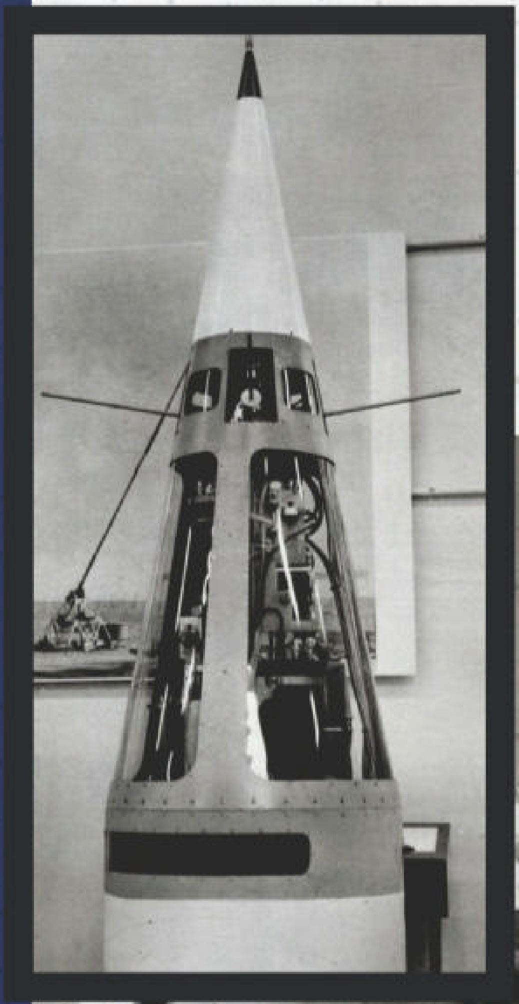
Eventually, the quiet little black-and-white cat called C 341 was chosen to be the feline Gagarin. Fatefully, one thing that swung the decision in her favour was that she was the only cat that was the required weight – all the other cats had managed to put on weight during their training.

By 18 October 1963 – launch day – C 341 had been fitted with even more sensors. To complement a microphone fitted to the rocket's nose cone, another microphone was attached to her chest to allow the teams on the ground to monitor her breathing. More electrodes were fitted to her front left leg and her right back leg to monitor her cardiac activity. Finally, another pair of electrodes was fitted to a foreleg, which would provide C 341 with 'stimulation' – via electric shocks – during her flight.

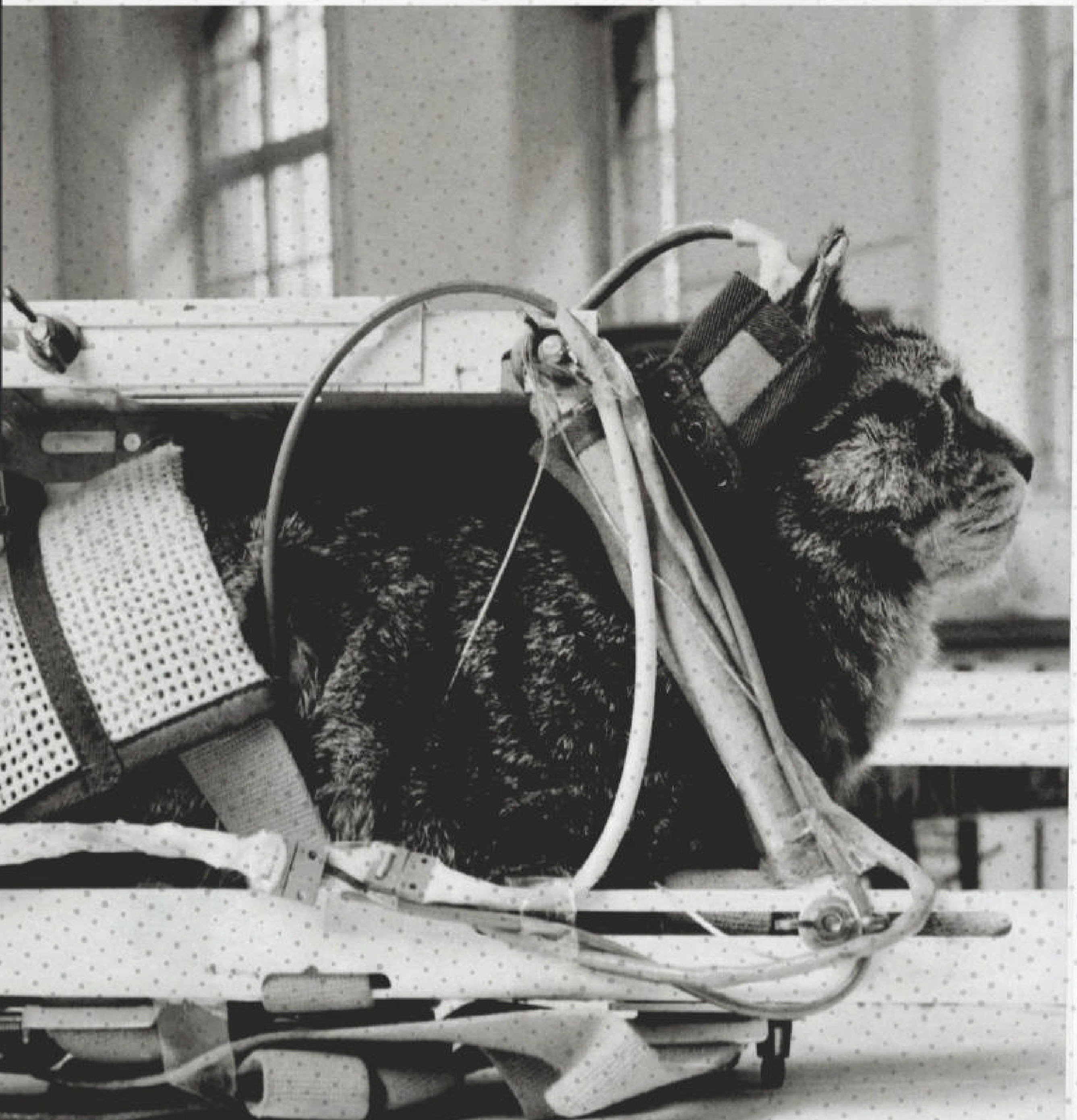
The Véronique wasn't standing waiting on a traditional launch pad. There was no tall skyscraper of scaffolding, no walkways or girders supporting it on one side. Betraying their V2 heritage, Véronique rockets launched from out in the open, like large model rockets.

Finally, at just after 08:00 local time, the 'go' command was given to launch. The leads and hoses were wrenched out of C 341's ride into space. No great bursts of orange fire billowed out of trenches beneath it in slow motion. The Véronique just shot up into the sky like the glorified firework it was. Moments later the quartet of support struts were jettisoned, falling away like sticks, and the rocket continued up into the sky with C 341 inside.

The Véronique's engines fired furiously for 49 seconds, pushing the rocket skywards with such power that, cocooned inside her capsule, C 341 experienced acceleration forces of 9.5 g. To put that into context, the Moon-bound Apollo astronauts strapped into their mighty Saturn V experienced



© Getty



© Getty

Far left: Félicette had no option to move during her cramped launch and flight on the Véronique

Left: All the cats were fitted with devices that allowed scientists to track their brain activity only four g during launch. Their successors, riding aboard the rather more luxurious Space Shuttles, felt only three g. In 2008 the three crew members of the Expedition 16 mission to the International Space Station experienced a force of eight g as their Soyuz capsule plummeted to Earth off course. Two of the three were injured, with one requiring treatment in hospital. So for a small cat to experience a chest-crushing 9.5 g must have been an incredible strain – and terrifying too.

The Véronique rocket reached the highest point in its trajectory at an altitude of 152 kilometres (94 miles). That's an important figure because it means that although Félicette didn't go into orbit around the Earth – as Laika had done in Sputnik 2 – the Véronique's capsule and its feline passenger officially made it into space by crossing the Kármán line, the internationally agreed height of 100 kilometres (62 miles) at which 'space' is said to begin.

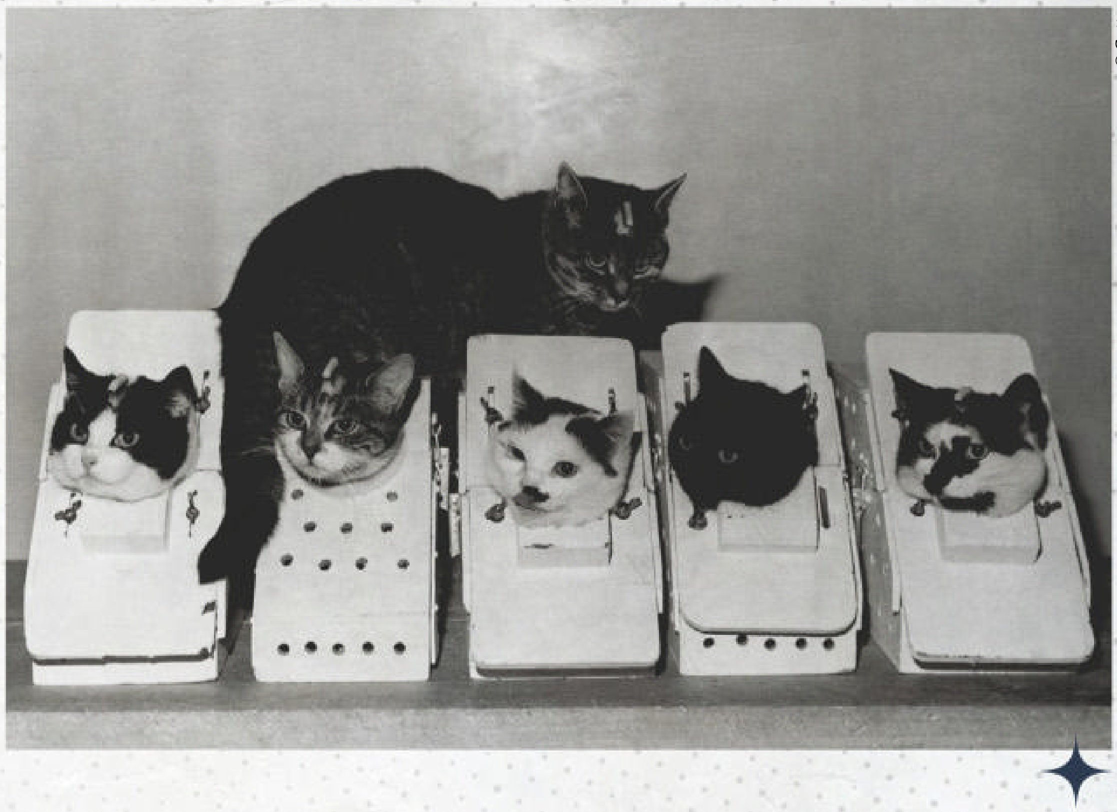
In films you can always tell when a spaceship has reached that magical place called 'space': the stirring background music is replaced by a cheesy angelic choir as the people in the ship all stop talking and turn to look at something in the cabin that is suddenly rising up into the air – a pen, a flight manual or something like that. Then, as they see their own hands lifting up slowly, they grin and unbuckle their clinking harnesses, and as they float up out of their seats as gravity's hold loosens, arms and legs flailing, they laugh like children locked in a toy shop. But inside her capsule, C 341 was strapped into her dolly in the pitch black so tightly there was no chance of her floating anywhere. She couldn't even move.

C 341 was 'in space' for around five minutes. With insufficient power to carry it on into orbit, the rocket began to descend again. Now it was time for the capsule to separate from the rocket in preparation for landing. It was jettisoned, and inside it C 341 experienced 'only' seven g before, 8 minutes and 55 seconds after launch, the capsule's parachutes opened and it began to fall rather more slowly towards the ground, swinging and swaying beneath its fluffed-out canopies.

13 minutes after it had been blasted off the ground atop its Véronique rocket, the capsule landed back down on the ground. It landed on its side, so C 341 was left pitched forwards inside it in her dolly, with her head facing down and her bottom sticking up in the air. She must have been very uncomfortable while she hung upside down like that, waiting to be rescued.

With the flight completed, the first scientific results collected and C 341 safely back on the ground – and, according to one video account, happy enough to be able to tuck into her food again – it was time for France to let the media and the world know about their achievement. Soon everyone knew C 341's story – and soon she had a proper name, too.

Right: You can see Félicette looking rather unhappy on the far left


©Getty

When the French media ran the story they were understandably very excited. It was a triumph for France, its scientists and engineers. With C 341's picture on the front pages of French newspapers, inevitably she was given a nickname – Felix, after the mischievous black-and-white cartoon cat which was hugely popular at the time. Of course that was wrong, as C 341 was female, so this was modified to the feminine version, Félicette.

Finally, having been dubiously sourced from somewhere without bearing a name and after months of training where she was referred to only by her number, C 341 had a proper name, pronounced 'Fay-lee-set'. Within days her name was everywhere. She was a heroine. But Félicette would not enjoy any of her post-flight fame.

Félicette returned from her flight in perfect health. In fact, after all her training and dieting, she'd probably never been fitter in her life. She still had many good years ahead of her, and an unknown number of her nine lives remaining, but she would never live them. Two months after her spaceflight, Félicette was killed so scientists could carry out a post-mortem to see how her body had been affected by her trip into space. They would later admit they learned nothing from the autopsy, and very little from the flight itself.

Félicette is a true forgotten figure of the Space Age. Today there is a statue in her memory at the International Space University campus, and she is mentioned more often in books and magazines, but her flight is still only a footnote in the story of the early years of the Space Race – but her story deserves to be told every bit as much as Laika's.

Stuart Atkinson
Science and astronomy writer
Stuart is the author of *A Cat's Guide to the Night Sky*, published by Laurence King Publishing. He has been observing the night sky for many years

Below: A statue at the International Space University celebrates Félicette

© ISU

WEIRD NEARBY GAMMA-RAY BURST DEFIES EXPECTATIONS

This isn't how they're supposed to behave

Reported by Meghan Bartels

Scientists have gotten their best look yet at a gamma-ray burst, the most dramatic type of explosion in the universe.

Astronomers think some of these explosions occur when a massive star - five or ten times the mass of our Sun - detonates, abruptly becoming a black hole. Gamma-ray bursts may also occur when two superdense stellar corpses called neutron stars collide, often forming a black hole. And, conveniently, a gamma-ray burst that scientists watched during a few nights in 2019 likely occurred only about 1 billion light years away from Earth, relatively close by for these dramatic events.

"We were really sitting in the front row when this gamma-ray burst happened," said Andrew M. Taylor, a physicist at the Deutsches Elektronen-Synchrotron (German Electron Synchrotron, or DESY). "We could observe the afterglow for several days and to unprecedented gamma-ray energies."

Two space-based NASA observatories, Fermi and Swift, first detected the event, which is known as GRB 190829A because it was detected on 29 August 2019. The fireworks came from the direction of the constellation Eridanus, a large swath of sky in the Southern Hemisphere. When the scientists behind the new research heard about the gamma-ray burst detection, they mobilised a set of five gamma-ray telescopes in Namibia, called the High Energy Stereoscopic System (HESS). Over three nights, the telescopes observed the explosion for a total of 13 hours in an attempt to understand what took place.

With those observations, the scientists could analyse much higher energy photons than is possible in more distant gamma-ray bursts. "This is what's so exceptional about this gamma-ray burst," said Edna Ruiz-Velasco, an astrophysicist at the Max Planck Institute for Nuclear Physics in Heidelberg. "It happened in our cosmic backyard, where the very-high-energy photons were not absorbed in collisions with background light on their way to Earth, as happens over larger distances in the cosmos."

During analyses, the team noticed that the patterns of X-rays and very-high-energy gamma rays matched - something scientists didn't expect, since they believe different phenomena cause the two different types of radiation. But so far scientists have only observed four of these bright explosions from the surface of Earth, so they're hoping that new instruments and additional observations give them more insight into the details of gamma-ray bursts.

Above: Due to its proximity to Earth, scientists received clearer data of the GRB

> “WE COULD OBSERVE THE AFTERGLOW FOR SEVERAL DAYS AND TO UNPRECEDENTED GAMMA-RAY ENERGIES”
>
> ANDREW M. TAYLOR

Food in Space

PLANNING OUT MARTIAN MENUS MEANS IMPROVING SPACE CUISINE

Reported by Andrew Webb and Daisy Dobrijevic

© Getty

Before Robert Behnken and Douglas Hurley blasted off in May 2020 aboard SpaceX's Endeavour, they had the traditional astronaut breakfast of steak and eggs. It's one of NASA's many food traditions, but for this particular breakfast at least, there was science behind the menu choice.

Steak and eggs washed down with orange juice, and notably tea, was served to the first American in space, Alan Shepard, on 5 May 1961 before his launch in Freedom 7. According to the NASA archive, no coffee was allowed 24 hours before the flight, as it might have kept Shepard awake, and he still wasn't allowed any at breakfast because of its diuretic properties. The menu was designed by Beatrice Finkelstein of the Aerospace Medical Laboratory and contained little fibre to be 'low residue', which in medical parlance means fewer, smaller bowel movements.

Shepard's flight time was only 15 minutes, so he didn't need to eat anything while in space. But a few weeks before, Yuri Gagarin was the first person to do just that on his 108-minute flight, sucking beef and liver paste from a tube. Before Gagarin's flight, scientists weren't sure if swallowing in zero gravity was even possible. During the decades that followed, astronauts' time in space grew into days, months and sometimes years, so the need for both sustenance and sanitation became critical.

The Apollo missions provided not only a giant leap for humankind, but also one for gastronomy when NASA invented the spoon-bowl pack for flights to the Moon. These plastic bags contained dehydrated food that was reconstituted by adding hot water via a valve. An article in *Nutrition Today* magazine from 1969 quoted one NASA scientist saying: "The variety was satisfactory, and there was enough to satisfy their hunger and maintain their performance," though that's hardly a ringing endorsement of space food's taste. "No one goes to space for the food... but the views are amazing," says Shuttle astronaut Don Thomas. Thomas flew four Shuttle missions in the 1990s, totalling 44 days in orbit. "Space food is a lot like camping food. It's freeze-dried or irradiated."

Cooking in space still often means injecting hot water into a pouch, though the Space Shuttle had a small convection oven that blew hot air over the irradiated meals to heat them up. The International Space Station (ISS) now has an induction oven.

Scientists have realised food is more than just fuel for astronauts – it plays an important role in their mental wellbeing and can be a reminder of home. "We were allowed to carry a snack to the launch pad in case of things like weather delays," says Thomas. "My favourite food is pizza, so I said, 'can you make me a pizza instead?' And NASA did. "I think it was the first pizza ever flown in space."

> "NO ONE GOES TO SPACE FOR THE FOOD… BUT THE VIEWS ARE AMAZING"
>
> DON THOMAS

SPECIAL ORDERS

Certain culinary considerations have to be made in space

LUCKY PEANUTS

The NASA Moon probes Rangers 1 through 6 all failed, so the pressure on JPL for Ranger 7 to be a success was huge. Mission trajectory engineer Dick Wallace thought passing out some peanuts might help calm things down. The flight was successful, and peanuts have featured at several launches or touchdowns ever since.

TEA AND COFFEE

There's no separate way to add creamer, sugar or sweetener to your hot beverage of choice, so every astronaut on the ISS has to let the food science team know how they like their drink before launch. All the astronaut has to do is add hot water.

CHILLED OUT

There's no food freezer on the ISS, but there is MERLIN. This cooler is designed for science experiments and provides a temperature-controlled environment between -20 and 48.5 degrees Celsius (-4 and 119.3 degrees Fahrenheit), but the crew can also use it for chilling drinks and foods.

LUNAR PALACE 1

China's Yuegong-1 created a menu of cultivated plants and insects mixed with externally supplemented foods that fed three humans for 105 days.

CUTLERY IN SPACE

Each astronaut gets their own utensil pack featuring a knife, fork, spoon and scissors. Most astronauts find the spoon and the scissors the most useful. There's no kitchen sink or dishwasher – utensils are cleaned with wipes after eating.

APOLLO 10'S FLOATER

During the Apollo 10 mission to the Moon, a stray stool was found floating through the capsule, having escaped from a waste bag. John Young, Eugene Cernan and Tom Stafford couldn't ascertain whose it was.

SALT AND PEPPER

Salt and pepper have to be in liquid form, or people could breathe it in or it could get in their eyes. The salt is dissolved in water and the pepper in a food-grade oil.

WOULD YOU LIKE TO SEE A MENU?

NASA now has a menu of 200 dishes and beverages, and crews get to taste and score each one in four sessions so their menus are made up of foods they like.

© Getty

FANCY SPACE TIPPLE? NOT ON NASA'S WATCH

Booze is strictly forbidden on the ISS for a whole number of reasons. An inebriated astronaut in control of a billion-dollar space station hurtling through space isn't a very good idea, but alcohol can also damage the ISS in other ways. Alcohol-containing products such as mouthwash and hand sanitiser are also banned, as the alcoholic compounds they contain affect the station's water-recovery system. Ethanol is a volatile compound and could cause damage to valuable equipment on the ISS.

Despite the dangers of alcohol in space, it wasn't always taboo. At the start of the Space Race, alcoholic drinks were included in cosmonaut rations. Small amounts of cognac were said to be recommended by Russian doctors to help the immune system. The ban only led to more inventive ways to sneak it aboard.

Chris Carberry details the various smuggling methods, as described by former cosmonauts and astronauts, in his book *Alcohol in Space: Past, Present and Future*. Alcohol was smuggled in hollowed-out books, 'mislabelled' juice cartons and even in pouches in spacesuits.

Today alcohol is deliberately sent to the ISS for science. A recent study sent bottles of red wine to the ISS, where they were stored for over a year. Upon their return to Earth they were compared with bottles that had not been sent to space. Scientists compared them, suggesting that wine in space may age faster. More alcohol-based experiments are planned to be carried out, including investigating the effect of microgravity on grapevine growth, as well as the effects on bacteria, yeast and fermentation processes.

© NASA

© NASA

© Karen Nyberg

Above: Astronaut Karen Nyberg enjoys some food and drink on the ISS

Right: A cracker floating on board the ISS

In 2016, UK astronaut Tim Peake famously took his favourite food to space: a bacon sandwich created by chef Heston Blumenthal. Bread can be particularly tricky in zero gravity, as it can leave crumbs that can interfere with sensitive equipment, so many astronauts today choose flatbreads and tortillas. Astronaut Terry Virts even created his own 'space cheeseburger', putting a beef patty, cheese, tomato paste and Russian mustard in a tortilla wrap. With the ISS came more room, better support facilities and longer mission times, and so food became better and more varied. Astronauts now get several fresh food deliveries, as well as growing a few crops like lettuce.

With NASA and others wanting to send humans to Mars, the food question just got a lot more complicated. Vickie L. Kloeris was a food scientist at NASA's Jet Propulsion Laboratory (JPL), and until her recent retirement led the food science team at NASA during the Shuttle era through to the ISS. She recently highlighted some of the issues of feeding astronauts on route to Mars.

First is how long a mission to Mars will take. Just travelling there takes around seven months, and another seven to get back. You'd also want to spend significant time on the Red Planet itself. What's more, you can only realistically go or return roughly every two years, when Earth and Mars' orbits are closest. Even a back-of-an-envelope calculation reveals that three meals a day for a crew of four for over four years is a huge amount of food; far too much to take in one go. Clearly food supplies will have to be pre-positioned.

This leads on to the second problem: shelf life. Food will have to maintain optimal nutrition and integrity for over five years. "You wouldn't want to launch the crew until you knew those pre-positioned supplies were in place," said Kloeris.

"We can make food that will control microbial growth, but we can't control the chemical changes. They will change the quality and nutritional content of the food," she adds. A further factor is how exposure to radiation in deep space may affect the quality of the food.

One particular area of concern is degradation in foods containing vitamin C. "Many nutrients stay stable, but some do not. One of the ones that's a challenge is vitamin C," says Kloeris. A lack of vitamin C causes scurvy, which plagued

> "YOU WOULDN'T WANT TO LAUNCH THE CREW UNTIL SUPPLIES WERE IN PLACE"
>
> VICKIE L. KLOERIS

THE OTHER END OF EATING IN SPACE

What goes in must come out – and scientists are getting creative with waste-disposal methods

Of course, food consumption is just the start of a complex set of digestive processes that end – quite literally – at the other end. With no gravity, going to the toilet in space is a tricky procedure. On Glenn's first flight there were no provisions, and after a launchpad delay, he ended up urinating in his suit. Apollo astronauts didn't fare much better, having to use a combination of absorbent pads, sheaths and bags – not always successfully.

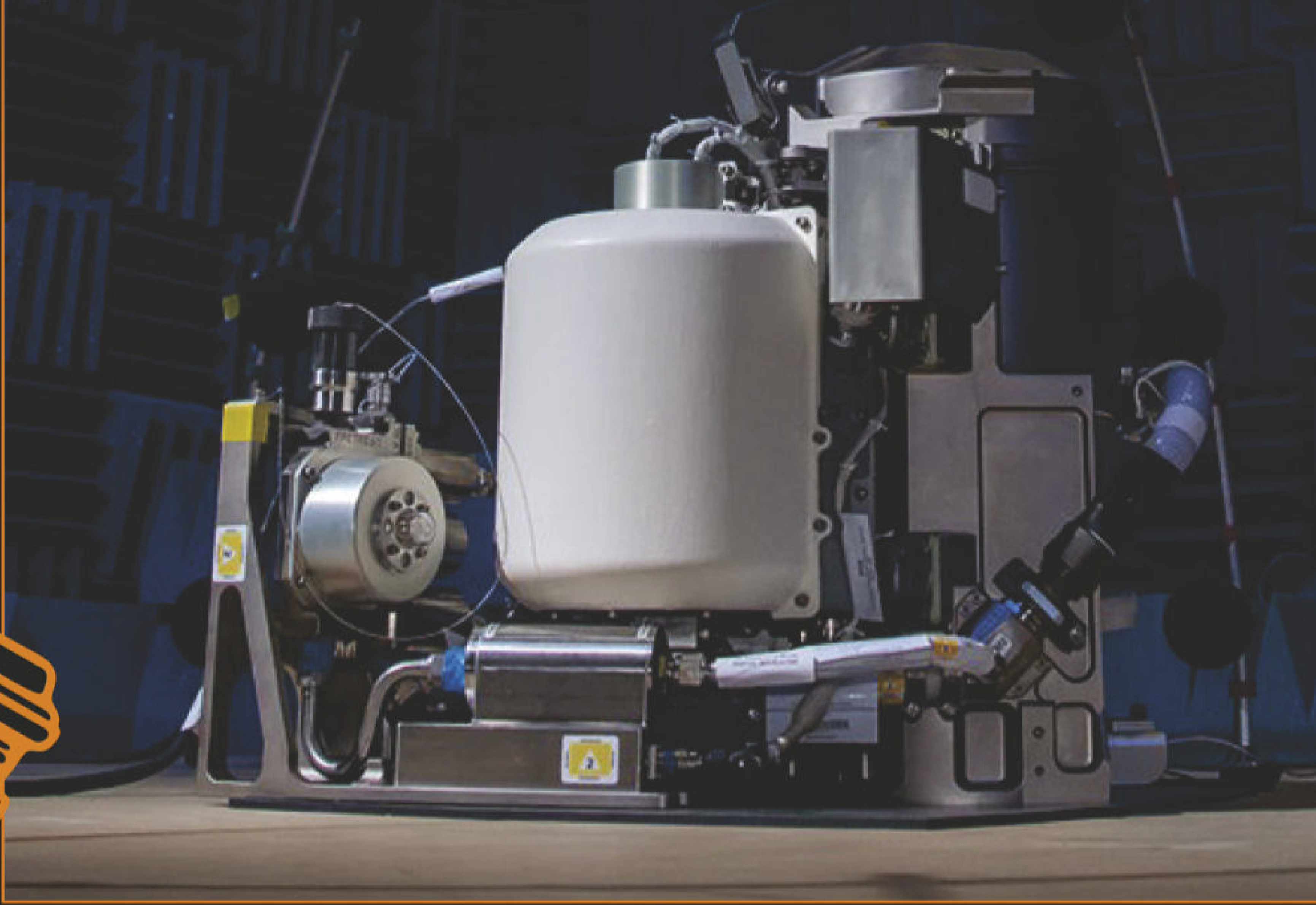
A document by NASA entitled *Biomedical Results of Apollo* states 'the principal problem with both the urine and faecal collection systems was the fact that these required more manipulation than crewmen were used to in the Earth environment and were, as a consequence, found to be objectionable'. Apollo 7 astronaut Walter Cunningham estimated the time required to correctly accomplish the process was around 45 minutes.

Fast forward to today and there are two toilets on the ISS, in both the Russian and US sections, and since 2008 urine – and other waste liquids from showers and condensation – have been recycled into drinkable water.

NASA is planning to return to the Moon by 2024 with the Artemis program, so in June 2020 it launched the Lunar Loo Challenge, offering a prize of $35,000 (£25,000) to anyone who could design the ultimate loo. "The key driver for this toilet compared to other very capable current toilets like the Universal Waste Management System (UWMS) is mass and volume," says competition organiser Michael Interbartolo. "Our toilet has to not only work in orbit around the Moon, but also on the surface of the Moon, and to get down to the surface takes propellant. There is a significant gear ratio of propellant to mass for items going down to the Moon and back up again, of around 10:1, so our toilet has a very low mass target of 15 kilograms, which is less than the standard two-piece toilet you have at home." Not only that, but it also has to work for both male and female astronauts and fit in a very small space, like on the Orion Capsule.

The crowdsourcing effort attracted over 2,000 submissions, and NASA awarded prizes to the top five participants. The first prize went to THRONE (Translunar Hypercritical Repository 1). The team presented a novel idea for a bladeless fan to entrain waste, as well as a method for bagging the waste which would minimise crew interaction with waste bags.

But how important is it to get this right? "Toilets are very important for crew wellbeing. Apollo had a very limited waste-management capability that the astronauts didn't like and had issues with. While going back to the Moon in 2024 is about starting the scouting for a permanent human presence, we wanted to ensure when that first woman and next man land at the south pole, going to the bathroom is not something they dread," says Interbartolo.



Above: The crew use a hose to collect urine. A funnel can be attached to the end of the hose

Left: NASA's new $23 million (£16.5 million) toilet was put to the test before being launched to the ISS in September 2020

x2 © NASA

AN ACQUIRED TASTE

While the choice of refreshments for astronauts has grown considerably in recent years, they continue to crave the spicier things in life – specifically hot sauce. Since the 1960s astronauts have noted that their taste buds don't work as effectively in space, and it's not uncommon for astronauts to find themselves enjoying cuisines in space that they couldn't eat at home, and vice versa. As such, a lot of work has gone into researching the science behind this and coming up with meals that satisfy the astronauts' hunger as well as enjoyment of the food itself.

Despite the continually updated menus and food choices, nothing seems to beat a good spicy sauce, or really any condiment that can add that extra kick of flavour. Former astronaut Peggy Whitson once wrote in her journal that her crew motto while on the ISS was: "It's all about the sauce." She went on to say that "a common question at lunch or dinner is 'What are you having with your sauce today?'.

But what causes this loss of taste that so many astronauts experience in space? It's thought that due to the lack of gravity, bodily fluids which would normally drain down to our legs become equally distributed around the body. This can lead to fluids building up in the head and blocking the nasal passages, similar to the congestion you can experience when you catch a cold.

As approximately 80 per cent of the flavours we taste actually come from what we smell, this congestion could explain why astronauts cannot taste the same flavours that they can on Earth. Another theory is that the ISS is filled with a whole range of strange smells, from body odour to sterile equipment. These aromas could distract the astronauts from smelling their own food effectively and getting the most out of the flavour. Either way, it looks like fiery and well-seasoned cuisine is essential for keeping astronauts well fed and happy.

© NASA

TAP HERE TO PLAY

"ANOTHER REAL DANGER IS MENU FATIGUE. WHAT CAN HAPPEN IS THAT PEOPLE EAT ENOUGH TO SURVIVE, RATHER THAN THRIVE"

VICKIE L. KLOERIS

Left: Collection of space food made in collaboration with Heston Blumenthal for astronaut Tim Peake's journey to the ISS

© UK Space Agency/European Space Agency
© The Board of Trustees of the Science Museum

18th-century explorers. Kloeris and the team at NASA found that powdered beverages enriched with vitamin C helped maintain optimal levels.

Assuming these quality challenges can be addressed, we come to the next problem: quantity. "Another real danger is menu fatigue," says Kloeris. "What can happen is that people eat enough to survive, rather than thrive." The US military has seen this happen with service personnel, and whether soldiers or scientists, teams need to be in good shape to complete their missions.

Though a lot of work, a mission to Mars lasting a few years is achievable with today's current technology and resources. But thinking long term towards a permanent base on Mars – and all the food and waste needs that come with that – is a Herculean undertaking.

Kevin Cannon is an assistant professor at the Colorado School of Mines and part of its space resources program. In late 2019, he and Daniel T. Britt published a paper titled *Feeding One Million People on Mars*. It examines what sorts of foods can be produced on Mars at scale and quickly. "I think the main challenge is making an early transition from imported supplies to locally produced food products using Martian materials. This will require a huge amount of enclosed, pressurised space with heating and lighting that needs to be newly constructed, or tunnelled out of the countryside," says Cannon.

Rearing meat would be fraught with ethical and technical problems, and so insects might be an alternative, which are easy to transport, keep and reproduce rapidly. Another option is 'cultured

© NASA

Left: Astronauts enjoying a group meal on board the ISS

Right: Terry Virts presents his 'space cheeseburger'

Below: NASA astronaut Loren Shriver eating M&M's while aboard the Space Shuttle Atlantis during the STS-46 mission in 1992

© NASA

© NASA

SNEAKY SNACK

A controversial and dangerous sandwich

Alcohol isn't the only banned substance that has been covertly transported into space. In 1965, John Young smuggled a corned-beef sandwich on the first crewed Gemini flight, Gemini 3, much to the surprise of his crewmate Gus Grissom. Just before launch on 23 March 1965, Young had hidden the sandwich in the pocket of his spacesuit. After Grissom enjoyed a quick bite of the sandwich during their flight, he quickly decided to put it in his pocket as it began to break up. According to the Gemini 3 transcript, Young suggested that the sandwich was "a thought… not a very good one", to which Grissom replied: "Pretty good, though, if it would just hold together." Corned beef later made an official appearance on the menu of the first Space Shuttle mission in 1981, of which Young was the commander.

meat' grown in a lab from cells. Also, the idea of large greenhouses full of tomatoes and lettuce so often depicted in science fiction doesn't really work either, with sunlight at Mars' equator comparable to that of Alaska. Consequently, crops will need artificial light to grow. The paper also highlights how the first settlers should concentrate on high-yield and high-calorie crops such as corn, wheat, sweet potatoes, soybeans and peanuts. Like astronauts today, menu fatigue remains a danger on Mars. "I think people tend to underestimate the importance of variety and just how closely food is tied to morale. You can only drink so much Soylent or live off re-hydrated meal pouches for so long before folks start to break down," says Cannon.

Establishing humanity on another planet would be a paradigm shift in our culture, and against the backdrop of current world events, it's apt to ask if humanity has the combined will and resources for this endeavour. If so, what sort of catalyst is it going to take to achieve it – new materials, pure science, adventure, tourism? Cannon concludes: "I think the main catalyst right now is the will of Elon Musk. He understands he has a very limited window to make this happen. The progress going on in Boca Chica is staggering, and will only get faster from here."

Andrew Webb
Food journalist and photographer
Andrew is a freelance food journalist who has worked for Channel 4 and the BBC, as well as *Waitrose Kitchen* and *Delicious* magazines

© NASA

Right: Astronauts Gus Grissom and John Young

PLANET PROFILE

MARS

The Red Planet has a host of new robots investigating it

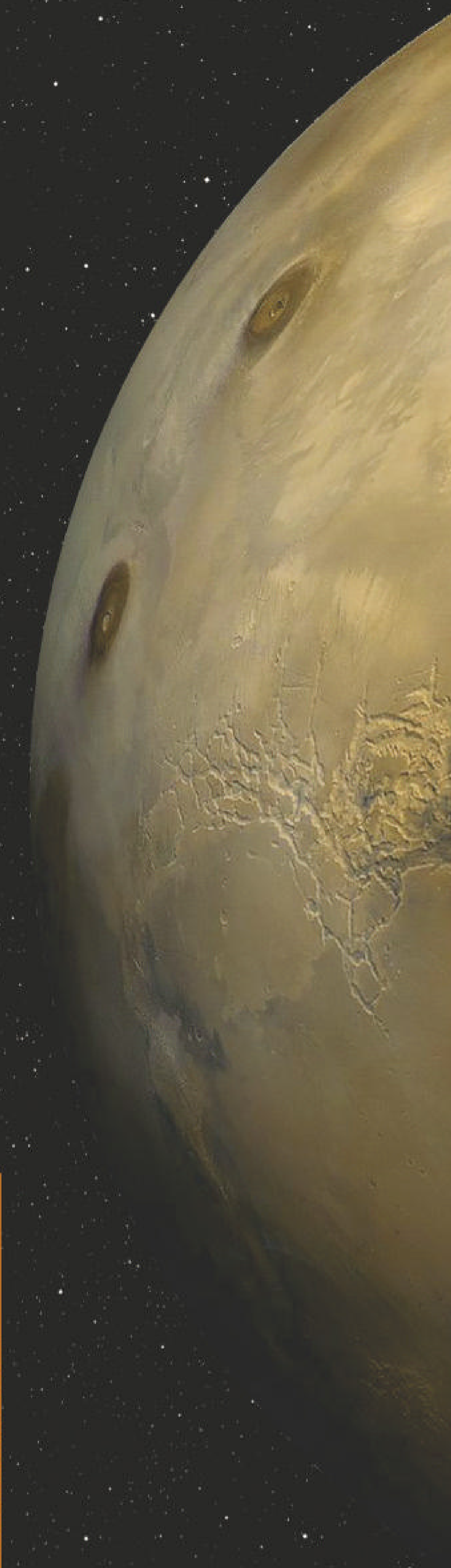
Across the gulf of space, no other planet has fired humanity's imagination so much as the Red Planet, and it has frequently been associated with violence, war and death. To the ancient Sumerians it was Nergal, a god of war and plague who presided over the netherworld. In Mesopotamia it was the 'star of judgement of the fate of the dead'. The Chinese associated it with the element fire, while for the people of the Tiwi Islands off the coast of Australia the planet was one of the four wives of the Moon Man, who followed the path of the Sun Woman through the sky - the other wives were Mercury, Jupiter and Venus. The planet was a familiar sight to the astronomers of ancient Egypt, Babylonia, Rome - where Mars was the god of war - and Greece, where Aristotle noticed that the planet vanished behind the Moon during an occultation, proving it was farther away.

Following the invention of the telescope in the 17th century, Mars could be observed in greater detail, and Christiaan Huygens was able to observe Syrtis Major - which he thought was a plain, but we now know to be a volcano - the first surface feature seen on another planet, in 1659. He was also able to measure Mars' day length as 24 hours and 30 minutes - only seven minutes short of the true value.

It would be another 312 years before a human-made spacecraft would touch down on Martian soil, with the Soviet Union's Mars 3 lasting 110 seconds on the surface and managing to transmit only part of a single image that showed no detail. There would be several more failures until NASA's Viking 1 touched down in 1976 and operated for over six years.

Exploration of the planet has continued, and right now there are three operational rovers on its surface. Curiosity and Perseverance are from the US, while Zhurong hails from China. These missions are the lucky ones. There have been a spate of failed missions from the USSR, US, UK and Japan - from rocket failures and solar panels failing to open to a mix-up between the units of measurement used in America and the metric system used by most of the rest of the world, which caused NASA's Mars Climate Orbiter to either burn up or skip off the Martian atmosphere and into deep space in 1999.

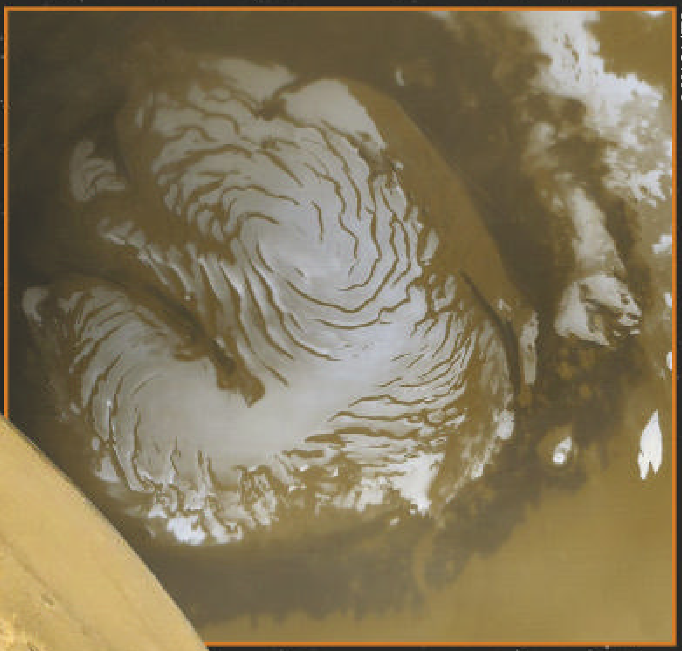
Human missions to Mars have been a dream since the earliest days of space exploration. In 2004 the Vision for Space Exploration announced by US president George W. Bush called for a crewed mission to the Moon in 2020 as a stepping stone to Mars. In 2007 NASA administrator Michael D. Griffin said the agency aimed to put a person on Mars by 2037. The Journey to Mars plan, formulated by NASA in 2015, uses the ISS and an asteroid captured in 2020 to test deep-space habitation facilities. That phase is behind schedule, but the ISS phase is underway and set to last until 2024. Humans on Mars in the 2030s is still NASA's goal.



© NASA

Left: Mars Pathfinder explores the rocky surface of the Red Planet

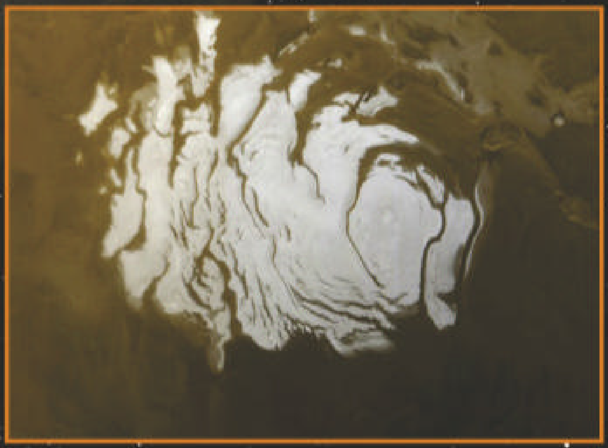
© NASA



© NASA/JPL

Above: Mars' north pole, taken by the Mars Global Surveyor

Below: Mars Global Surveyor image of ice at the south pole



© NASA/JPL

ATMOSPHERIC COMPOSITION

95%
CARBON DIOXIDE

2.6%
MOLECULAR NITROGEN

1.9%
ARGON

0.16%
MOLECULAR OXYGEN

0.06%
CARBON MONOXIDE

0.03%
WATER VAPOUR

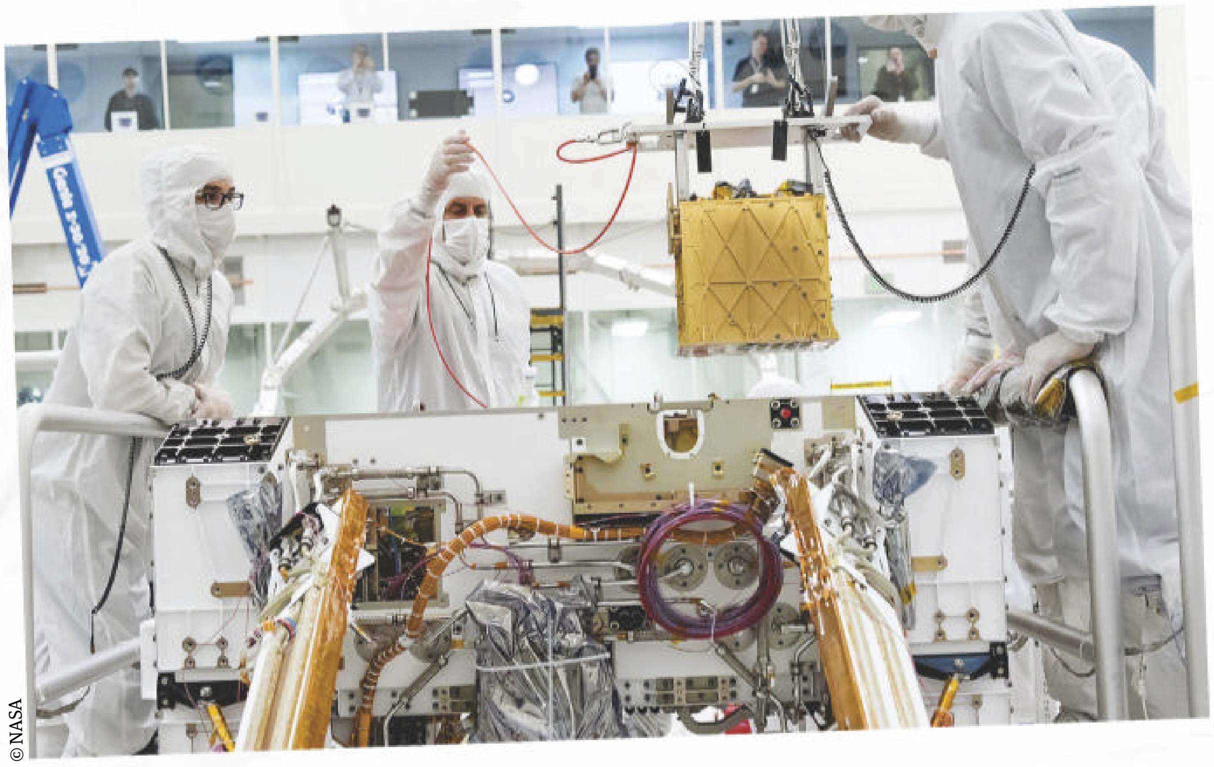
NEWS FROM MARS

Renewable energy on Mars

Renewable power is a little bit tricky on Mars, which is farther from the Sun, has dust storms and has no tides. What it does have, however, is wind, and so scientists from Delft University of Technology have come up with the excellent idea of designing robots to fly huge power-generating kites in the Martian atmosphere. "Despite the low density of the Martian atmosphere, wind speeds are high enough to make wind energy competitive with nuclear power in terms of power produced per unit mass," the scientists wrote in a research paper. One kite could generate 127 megawatt-hours of energy per year, the scientists say, enough to power five households in the US.

The assembly, which will also have solar panels – though Mars gets only 43 per cent of the sunlight we enjoy on Earth – will catch the wind and be reeled out, performing a series of tacking manoeuvres to maximise its speed and pulling force. This is all controlled by a robot that steers the wing-like kite, changing its angle of attack. Once the cable is pulled out, the kite can be dropped to minimise the pull as it's reeled back in, ready to fly again.

© NASA



© NASA

Oxygen on Mars

The atmosphere on Mars is thin and not conducive to effective human breathing. It's a hostile environment, and any astronauts who explore there will need to take their own oxygen. If humans are to build an outpost on the planet, however, they need a way of generating their own oxygen, which is also a critical component of rocket fuel. NASA estimates that to get four astronauts back from Mars would take about 25 tonnes of the gas.

Enter the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), carried aboard NASA's Perseverance rover. This uses 300 watts of power to heat carbon dioxide from the Martian atmosphere, where it strips the oxygen atoms away from the carbon and sends the resulting carbon monoxide back outside. During its first test in April, it created just over five grams of oxygen in an hour, which is about ten minutes of breathing for an astronaut. MOXIE is just a demonstrator, but larger, more powerful versions of it could one day produce enough oxygen for a colony.

Ingenuity wobbles, but flies on

The small robotic helicopter carried by NASA's Perseverance rover made its sixth flight across the Martian surface near the end of May, but it was a flight marked by control disruptions and power spikes.

The helicopter was asked to climb to ten metres (33 feet) above the surface before flying to the west to take stereoscopic images of a region of interest there. It had been flying for 54 seconds when a glitch was noticed in the stream of images coming from the navigation camera. Only one image was lost, but this led to the following images being delivered with inaccurate timestamps. Ingenuity uses an algorithm to navigate that uses both visual data about where things are and timestamps to tell it when it saw them.

As a result, Ingenuity began adjusting its velocity and tilting back and forth in an oscillating pattern, and this behaviour persisted for the rest of the flight. It encountered roll and pitch excursions of more than 20 degrees, large control corrections and spikes in power consumption. Despite this, the robotic aircraft was able to land within five metres (16.5 feet) of its intended location.

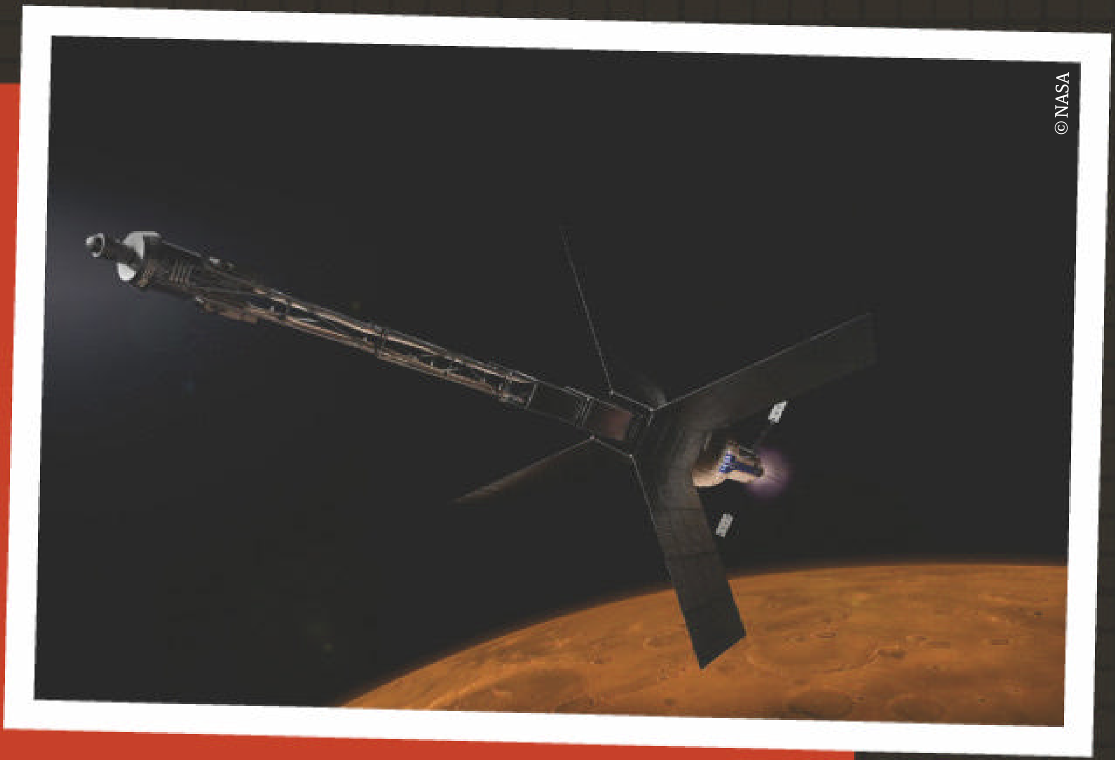
© NASA

NUCLEAR ROCKETS

All this talk of oxygen and energy is all well and good, but before you can start deploying these technologies on Mars you've got to get there. NASA has explored the Solar System using a range of chemical rockets and gas-fuelled manoeuvring systems, but is investigating two methods of nuclear propulsion to speed humanity to the Red Planet.

The first is nuclear electric propulsion, otherwise known as the ion drive, which supplies low thrust over a long interval to gradually build high acceleration. The other is nuclear thermal propulsion, which provides high thrust and twice the propellant efficiency of chemical rockets. NASA is looking into preliminary reactor design concepts for such a rocket, which heats a fluid, usually liquid hydrogen, in a nuclear reactor. Once it reaches a high enough temperature, the fluid expands through a rocket nozzle to create thrust.

Nuclear thermal propulsion has been on NASA's radar for more than 60 years. Research on the subject once concentrated on fission reactors, but these came with a number of problems, notably that no one wanted a flying fission reactor with even a chance of exploding over their heads. Recent research has moved to nuclear fusion power, and such a rocket could be constructed in orbit as an additional safety measure. Nuclear propulsion could enable missions to Mars at times when the planet is not favourably positioned relative to Earth, and could cut the round trip time of a crewed mission to just two years.


© NASA

Above: Illustration of a Mars transit habitat and nuclear propulsion system that could one day take astronauts to Mars

EVOLUTION OF THE RED PLANET

Date: 4.57 billion years ago
Activity: Mars was part of the same protoplanetary disc as the other planets, swirling around the nascent Sun.

Date: 4 billion years ago
Activity: The Late Heavy Bombardment scarred Mars' surface – these craters can still be seen today.

Date: 4 billion years ago
Activity: Mars was hit by a body the size of Pluto, creating the smooth Borealis Basin that covers 40 per cent of Mars.

Date: 3.8 billion years ago
Activity: Substantial amounts of liquid water on the surface began to dry up due to the loss of the planet's magnetic field and its atmosphere.

Date: 3.3 billion years ago
Activity: Olympus Mons, a huge volcano, formed as part of a period of enormous geological activity.

Date: 237 years ago
Activity: Astronomer William Herschel declared Mars would offer "a situation in many respects similar to ours".

Date: 144 years ago
Activity: Asaph Hall discovered Phobos and Deimos, the Martian moons.

Date: 50 years ago
Activity: Humans started dropping craft and robots onto the surface, but many of these fail.

MARS BY NUMBERS

15%
Mars is 15 per cent of Earth's volume

8 METERS
There is eight metres of permanent frozen CO_2 at the south pole

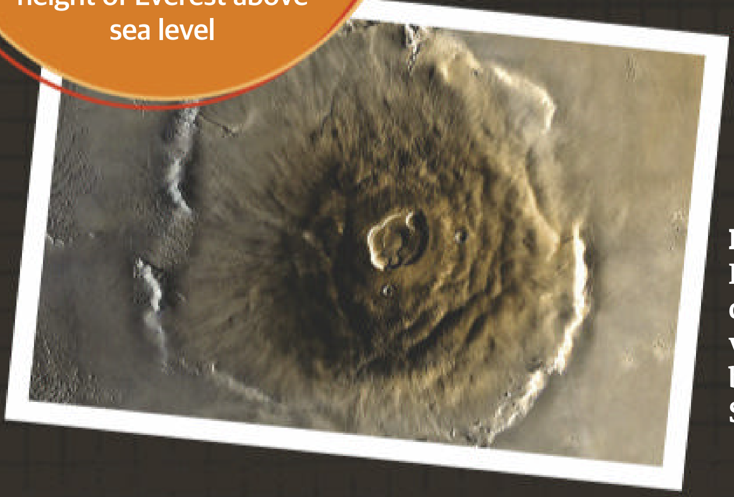
38%
Its gravity is 38 per cent of Earth's

70%
The polar caps are 70 per cent water ice

OLYMPUS MONS
The tallest mountain of any planet, it's 2.5 times the height of Everest above sea level

11%
Mars has 11 per cent of Earth's mass

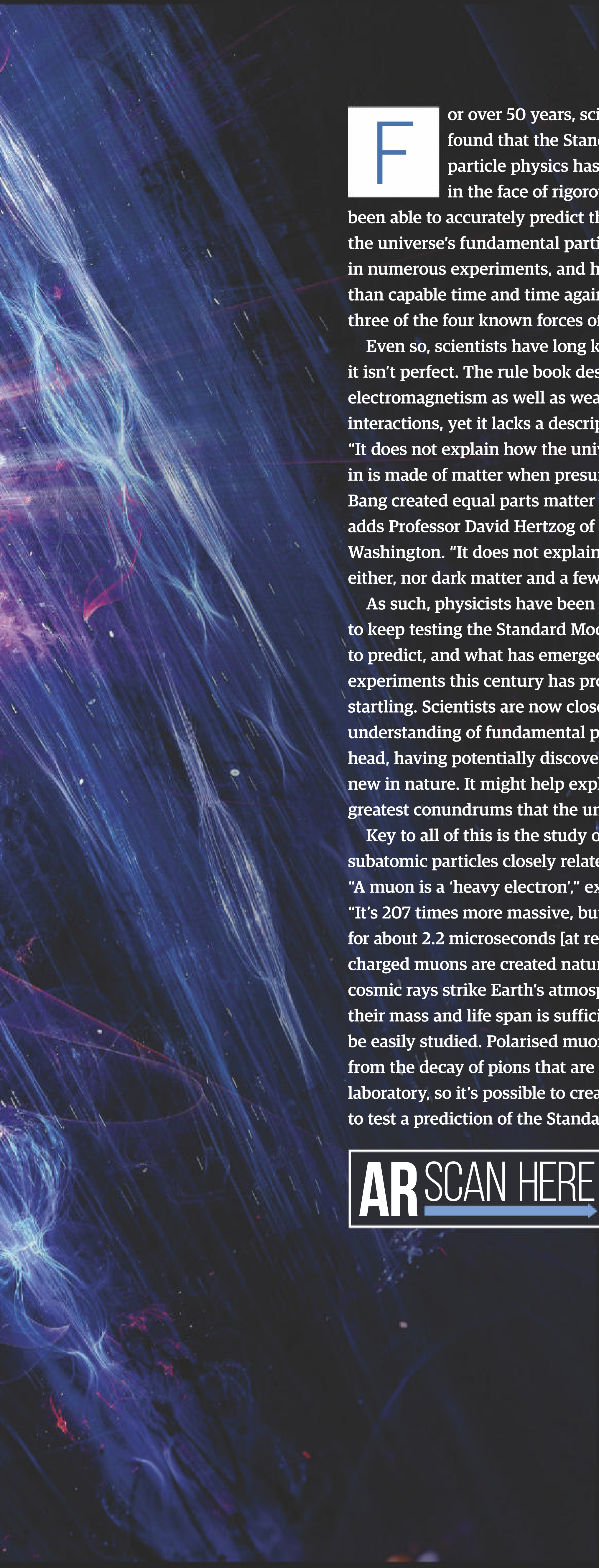
7.7
Its soil pH is 7.7, which is slightly alkaline


© NASA

Left: Olympus Mons is a dormant shield volcano, the biggest in the Solar System

REVOLUTIONARY EXPERIMENTS MAY POINT TO A NEW FORCE, OR AN UNDISCOVERED SUBATOMIC PARTICLE

HAVE SCIENTISTS DISCOVERED A FIFTH FORCE OF NATURE?


© Alamy

For over 50 years, scientists have found that the Standard Model of particle physics has performed well in the face of rigorous testing. It has been able to accurately predict the behaviour of the universe's fundamental particles, as shown in numerous experiments, and has proven more than capable time and time again of explaining three of the four known forces of nature.

Even so, scientists have long known that it isn't perfect. The rule book describes electromagnetism as well as weak and strong interactions, yet it lacks a description of gravity. "It does not explain how the universe we live in is made of matter when presumably the Big Bang created equal parts matter and antimatter," adds Professor David Hertzog of the University of Washington. "It does not explain neutrino mass, either, nor dark matter and a few other things."

As such, physicists have been motivated to keep testing the Standard Model's ability to predict, and what has emerged from experiments this century has proven rather startling. Scientists are now close to turning our understanding of fundamental particles on its head, having potentially discovered something new in nature. It might help explain some of the greatest conundrums that the universe presents.

Key to all of this is the study of muons – subatomic particles closely related to electrons. "A muon is a 'heavy electron'," explains Hertzog. "It's 207 times more massive, but it only lives for about 2.2 microseconds [at rest]." Electrically charged muons are created naturally when cosmic rays strike Earth's atmosphere, and their mass and life span is sufficient for them to be easily studied. Polarised muons also result from the decay of pions that are created in the laboratory, so it's possible to create and use them to test a prediction of the Standard Model.

AR SCAN HERE

In 2001, Hertzog was part of a team based at the Brookhaven National Laboratory in Upton, New York, which sought to do just that. A machine had been built at the location a few years earlier, consisting of a circular superconducting magnet. The experiment injected spinning muons into the magnet and observed their spin direction as they circulated in the field. "Muons go around the ring at one frequency, and their spin axes go around at a slightly faster frequency," explains Hertzog.

Physicists knew the muons would be affected by 'virtual particles' popping in and out of existence in the vacuum, and that this would alter the muons' wobble. In making their calculated predictions, physicists considered both the strength of the muons' internal magnets and their intrinsic property, 'spin', to calculate what's known as the 'g-factor', which is the relation between the two.

"We measure the frequency by employing detectors that sense the decay particles that are emitted in a pattern proportionate to that difference," Hertzog says of the 24 detectors that line the inner wall of the track. "We also need to know the magnetic field to equal precision, and we do that with nuclear magnetic resonance probes." The idea is to measure how frequently

ANOTHER EXPERIMENT OF CONCERN

Aside from the exciting work being carried out at Fermilab, scientists have been studying the trillions of collisions produced using the Large Hadron Collider, CERN's atom smasher. They've noted that unstable particles – or B mesons – created in the machine should, according to the Standard Model, break down into products that include electrons and muons in equal measure.

Instead more electrons are found, pointing to a failure in the Standard Model's predictions. In theory, a 15 per cent difference in favour of electrons – that is, 85 muon decays for every 100 electron decays – could only occur if never-before-seen particles are affecting the decay in some way. Even so, the results in this case have a three-sigma chance of being a random fluke in the data.

the decay particles are being detected, which lets the researchers determine the rate at which their muon is wobbling.

When the experiment was undertaken, however, the muons - to great surprise - were found to wobble 0.1 per cent faster than predicted by the Standard Model. The result was significant because it called the Standard Model into question. Crucially, it also suggested that unknown particles could be affecting the muons' behaviour.

Yet there was still a nagging doubt over the result. What if it was just a fluke? What if a mistake had been made somewhere along the line? Physicists said that there was a 1-in-4,500 chance that it was a random fluctuation, making it a significance of 3.7-sigma. That was some way off what would be deemed to be a discovery. Only a five-sigma - putting the chance of a fluke at just 1 in 3.5 million - could allow it to be labelled as such.

"Being 3.7 standard deviations different means it's 'a lot different'," affirms Hertzog. "But many people question that it's just one experiment, and if the theory is really right and so on. So the idea was to do a more modern version of the experiment with 20 times as much data, improved conditions, better instrumentation and see if the deviation still exists. That's just good scientific practice." And so it was that the experiment needed to be repeated.

"Our last paper from the Brookhaven National Laboratory was published in 2006, but the last data was taken in 2001," he continues. "Once we published the 2006 'final paper', we already knew we had to launch an improved experiment, and several physicists joined forces to plan it. It's been a lot of years of waiting."

In 2013, bold physical steps were taken to make a second, improved experiment happen. Scientists from 26 institutions backed a plan to move the electromagnetic ring from New York to the US Department of Energy's Fermi National Accelerator Laboratory in Illinois. It was far less expensive to move the ring than construct a new one, even though it was a mammoth task that involved taking the superconducting electromagnetic storage ring in one single piece across roads and water.

To give an idea of how tricky this was, the ring is 15 metres (50 feet) in diameter, and it couldn't be nudged by more than a few degrees without risking irreparable damage to the interior wiring. It took a couple of months to complete the journey, working in the dead of night so that there was far less risk of being caught

> "THE IDEA WAS TO DO A MORE MODERN VERSION OF THE EXPERIMENT WITH 20 TIMES AS MUCH DATA"
>
> DAVID HERTZOG

Source: Wikipedia Commons © Reidar Hahn

AMAZING MUONS

Muons are the cousins of electrons, but what else do we know about them?

1 THEY DON'T LIVE LONG

Muons have an average lifetime of just 2.2 microseconds. To put that into perspective, there are a million microseconds in a second.

2 THEY CAN PASS THROUGH OBJECTS

And that includes you! Muons have strong penetrative power, and about 10,000 of them pass through our bodies every minute.

3 THEY CAN BE MADE IN A LAB

Although muons were discovered in 1936 as a product of cosmic rays hitting the atmosphere, they can also be made in particle accelerators.

4 THEY ARE RATHER HEAVY

In comparison to electrons, at least. Although muons have the same negative charge as electrons, they have 207 times the mass.

5 THEY DECAY INTO OTHER PARTICLES

A muon decays into an electron and two neutrinos. Electrons, on the other hand, don't decay into other particles.

6 THEY TRAVEL IN STRAIGHT LINES

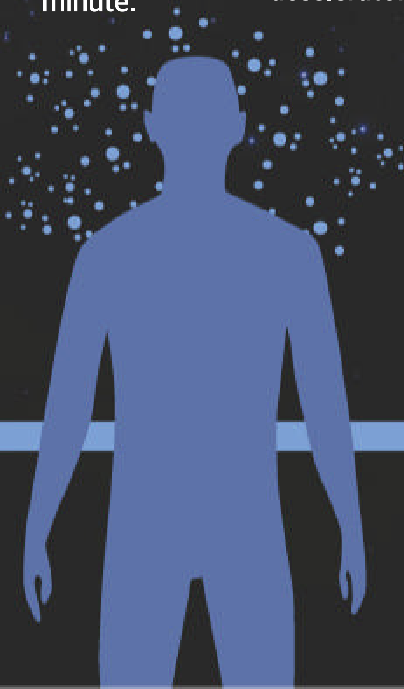
They can also be absorbed by dense materials such as stone. Muon-imaging techniques have been used to study the interior of pyramids and volcanoes.

7 THEY INTERACT WITH FORCES

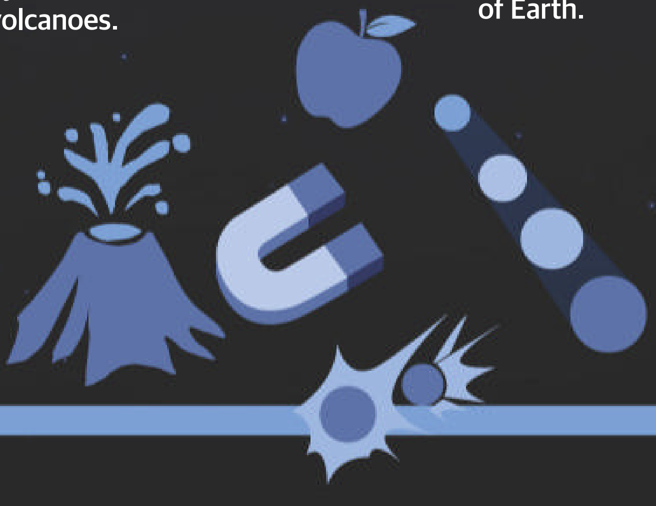
Muons interact with gravity, electromagnetism and the weak force. It's their interaction with the weak force that causes them to decay.

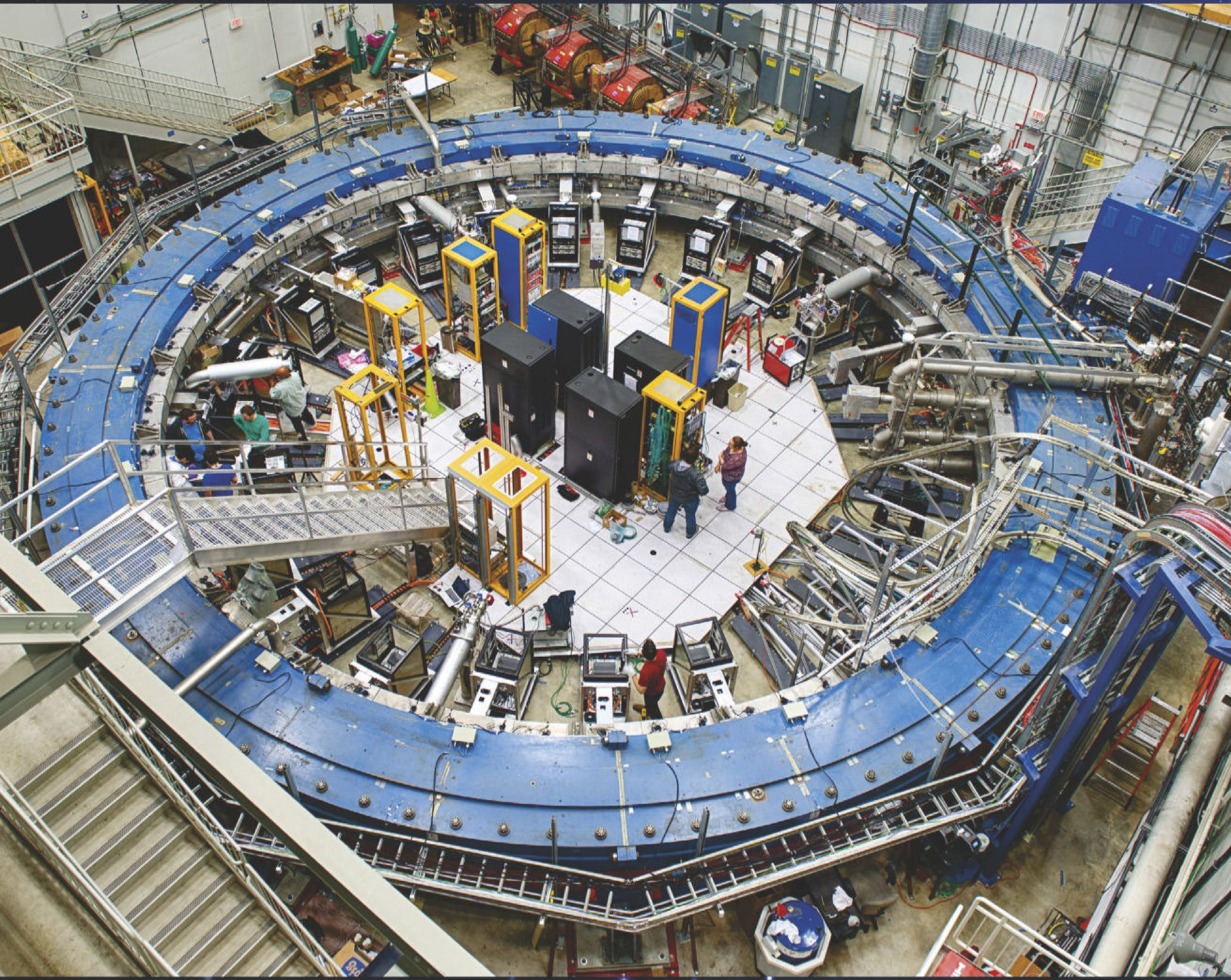
8 THEY MOVE VERY FAST

Muons move at close to the speed of light, which means they travel great distances in a tiny amount of time, only stopping about a mile beneath the surface of Earth.



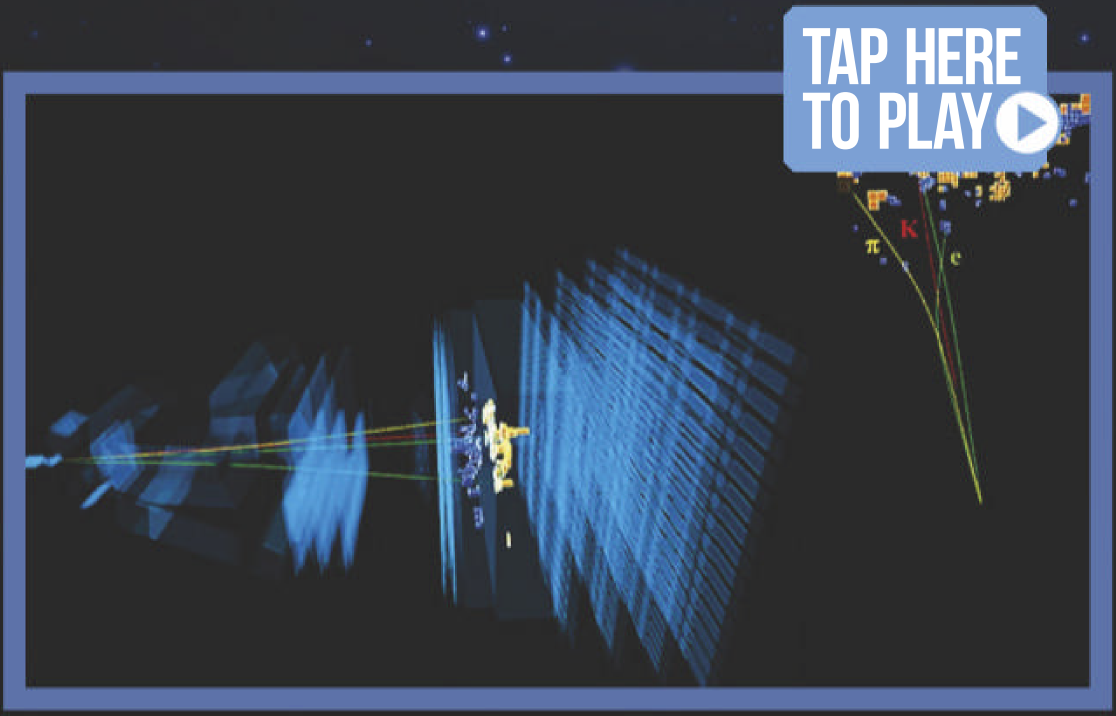
© Getty





up in a traffic jam – or, worst case scenario, a collision with another vehicle. But the Muon g-2 experiment, as it's known, was about to get its second wind. Physicists were going to discover if the earlier test had led them up the wrong path, or if it was indeed spot on.

"Because nearly anything that extends the Standard Model might change the g-2 value, our experiment is a comprehensive 'survey' effort," says Hertzog. "If we find a deviation between Standard Model predictions and our measurement then we will know something interesting is going on, but it will take other complementary experiments and observations to pin down the reason. In contrast, if we



© CERN

Above: Fermilab's Muon g-2 storage ring, which sends particles around a ring before applying a magnetic field

Left: CERN has found unusual particle decay which also departs from the Standard Model eventually determine that the Standard Model prediction is correct, it will rule out a lot of speculative theories. It's quite powerful."

The key reason for moving the experiment to Illinois was to take advantage of Fermilab's particle accelerator. It has allowed the physicists to produce the most intense beam of muons possible in the whole of the US. The scientists didn't just hook everything up and get going right away, though. As well as ensuring the ring was operational, they spent time calibrating and fine-tuning a uniform magnetic field. They created computer simulations, worked on new methods and techniques and looked to ensure everything worked as it should to keep the chance of an error down to the bare minimum.

Again the experiment used a parameter called the g-factor, which is an indication of the magnet's strength and the rate of its gyration. The reason the experiment refers to g-2 is because it takes into account that the value of g is a little higher than two. Once more the focus was on using muons rather than electrons, and not just because the aim was to replicate and confirm the Brookhaven result.

"The electron, muon and tau are all leptons, and they interact by the electromagnetic and weak interactions as opposed to the strong interaction," explains Hertzog. "Muons are particularly convenient for a g-2 measurement because they are 'more sensitive' than electrons in testing the Standard Model. Even though you can make an electron g-2 measurement about 1,000 times more precisely, still the muon generally wins by a lot."

The experiment began in 2018, and more than 200 scientists from 35 institutions in seven countries were on their nerves' edge for much of the time thereafter, not always believing that they would achieve a similar result to before. And yet that is exactly what has happened.

In the magnetic field, the muons wobbled, and they did so faster than theorised in the Standard Model. "The rate that the spin axis advances is entirely dependent on the virtual fields the muon sees from all Standard Model particles that exist," says Hertzog. "Remarkably, this can be calculated to a precision as good or better than the experiment – at least for the particles we know about."

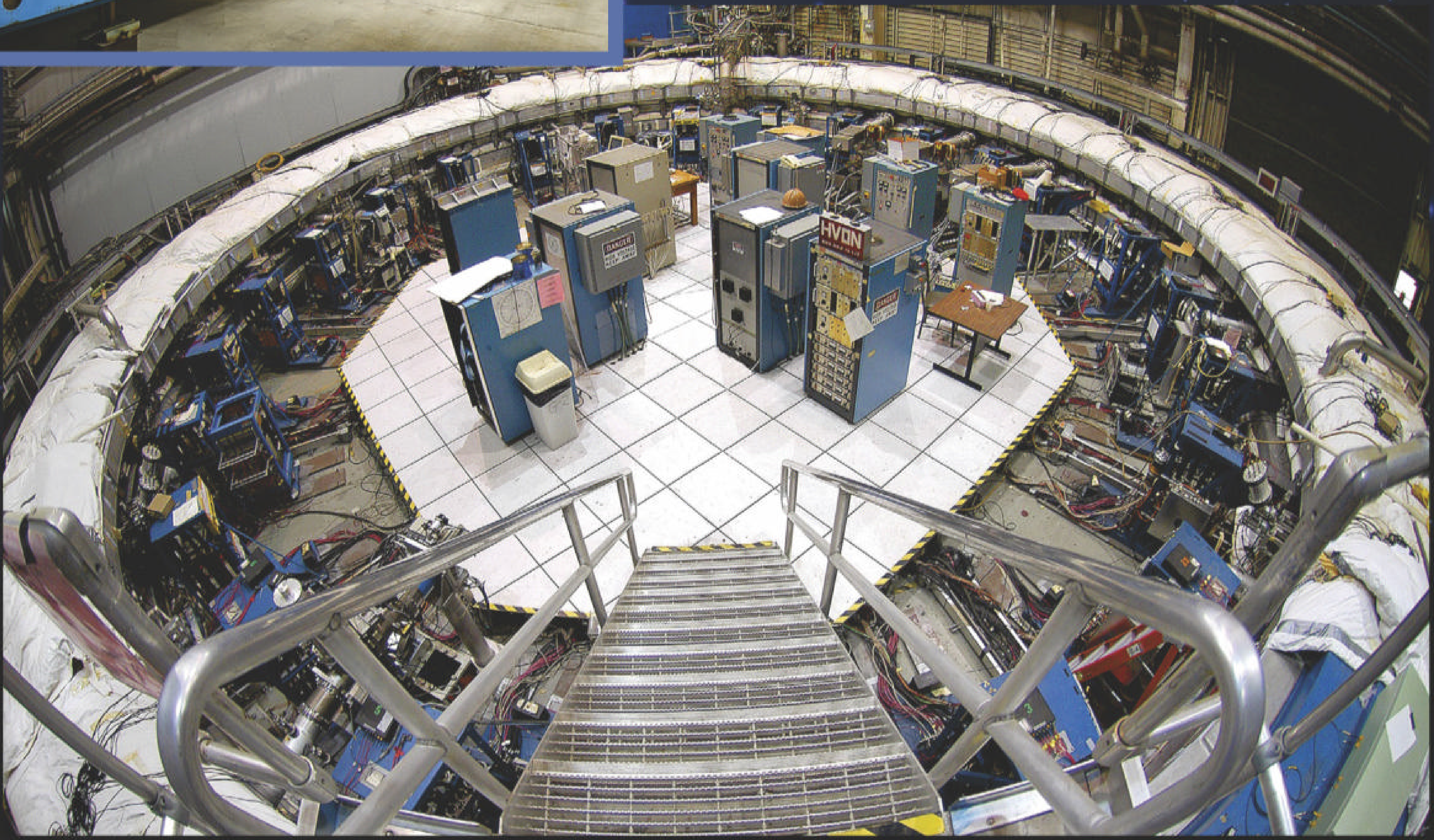
"MUONS ARE PARTICULARLY CONVENIENT BECAUSE THEY ARE 'MORE SENSITIVE' THAN ELECTRONS IN TESTING THE STANDARD MODEL"

DAVID HERTZOG

Below (top): In 2017 Fermilab set a world record for having the most powerful high-energy particle beam for neutrino experiments

Below: The Muon g-2 storage ring was originally constructed at Brookhaven National Laboratory

© Fermilab

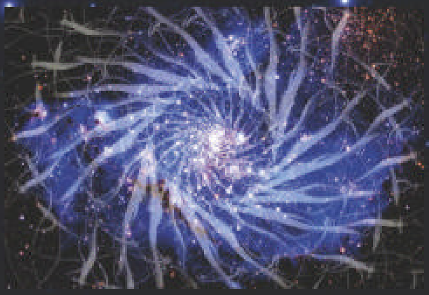

© Brookhaven National Laboratory

SOLVING CASES

What could the potential discovery tell us about the universe?

WHY IS THERE SO MUCH DARK MATTER?

About 68 per cent of the universe is made up of dark energy, while dark matter – which is thought to be the stuff that binds galaxies together – makes up about 27 per cent, the rest being everything we can observe. But why is there so much dark matter out there, causing galaxies to rotate faster than the gravity generated by their observable matter? It's a mystery that has occupied scientists for many years, yet the possibility that new particles exist may provide a connection that goes some way to explaining what dark matter is and how it functions.



WHERE HAS ALL THE ANTIMATTER GONE?

As the name suggests, antimatter is the opposite of normal matter. It's known that every subatomic particle of normal matter has a corresponding antiparticle, and that as the universe cooled and expanded following the Big Bang, matter and antimatter existed in equal amounts. It's not the case any more. As time went on, matter came to dominate the universe, and physicists aren't sure why the 50/50 split was lost. Could potential new particles hold the key to the large-scale disappearance of antimatter? It's something scientists will be considering.

IS THERE A FIFTH FORCE OF NATURE?

Numerous speculative theories proposing a fifth force of nature have emerged in the past, each seeking to explain why observations don't tie in well with existing theories. There's a school of thought that a form of dark energy could be a fifth force, for example, and following the Muon g-2 experiment, the UK's Science and Technology Facilities Council said there was "strong evidence for the existence of an undiscovered subatomic particle or new force". If proven, the muon wobble is certainly going to be creating new laws of physics.

x3 Images © Getty

The physicists are now able to combine the anomalies for a 4.2-sigma. It's still short of five-sigma, but now there is a 1-in-40,000 chance that something is skewing the results. "Our first result from the Muon g-2 experiment confirms the one from Brookhaven," continues Hertzog. "When combined, the new 'average' experimental result is now 4.2 standard deviations from theory, which has a lot of people even more excited."

There's a good reason for the excitement. "If the spin is faster than the Standard Model predicts, there must be something missing that we didn't include in the calculations," Hertzog explains. "There could be new particles or forces, and that would be very significant." Maybe it could lead us to revising theories such as dark energy, pointing, perhaps, to a new fifth force which is accelerating the expansion of the universe. At the very least, textbooks look likely to be on the verge of being rewritten, and something beyond the Standard Model may be needed.

As you can imagine – given that so much is riding on the results – more work is being done. The focus now is to keep refining and honing, getting ever closer to that all-important five-sigma. To prevent human mistakes from creeping in and distorting the outcome, the experiments have been carried out 'blind'. In fact, they've been done with multiple layers of blinding. "Because we measure frequencies, we actually have physicists outside our collaboration set the speed of our high-precision oscillators [that is, our 'clocks'], and we do not know the speed of the clock 'tick' until we are ready to publish the data," says Hertzog.

"That way we can do the entire analysis, set all the uncertainties, do all the data checks and not know the value of g-2. When we are done we all vote, open the paper envelopes that reveal the actual clock speed and compute the answer. It's a lot of pressure, but a very pure process. On top of that we have many other layers of internal software blinding factors so that independent teams must work in isolation until we arrive at agreed-on points of comparison."

As it stands, the g-factor can be calculated to 350 parts per billion, which is the same as the precision of the combined Brookhaven National Laboratory and Fermilab results. But, Hertzog says, both will be improving over the next few years. Scientists have also been increasing the precision with which the Standard Model can predict the rate of muon wobble. That way they can be absolutely sure the calculations aren't causing any problems – so far, they're not.

That said, physicists are still a couple of years away from acting with true certainty. "We have only looked at about six per cent of the data we hope to eventually obtain, and we have collected much more already on our goal," Hertzog says. "Our focus now is to analyse the additional data and see what we get. Will it continue to evade the Standard Model? That's the question. Meanwhile, the theorists are working on those improvements as well. Will their prediction change? We have to wait and see."

Below: The Muon g-2 experiment ring was moved from Brookhaven National Laboratory in New York to the Fermilab facility near Chicago

Source: Wikipedia Commons © Glukicov

JUPITER'S OCEAN MOON EUROPA MAY HAVE DEEP-SEA VOLCANOES

Jupiter moon may be an even more promising abode for life than scientists thought

Reported by Mike Wall

A new study suggests volcanoes may lurk on the seabed of Europa, which harbours a vast ocean of salty water beneath its icy shell. Active volcanoes could power deep-sea hydrothermal systems, environments rich in chemical energy that potential Europa life forms could exploit.

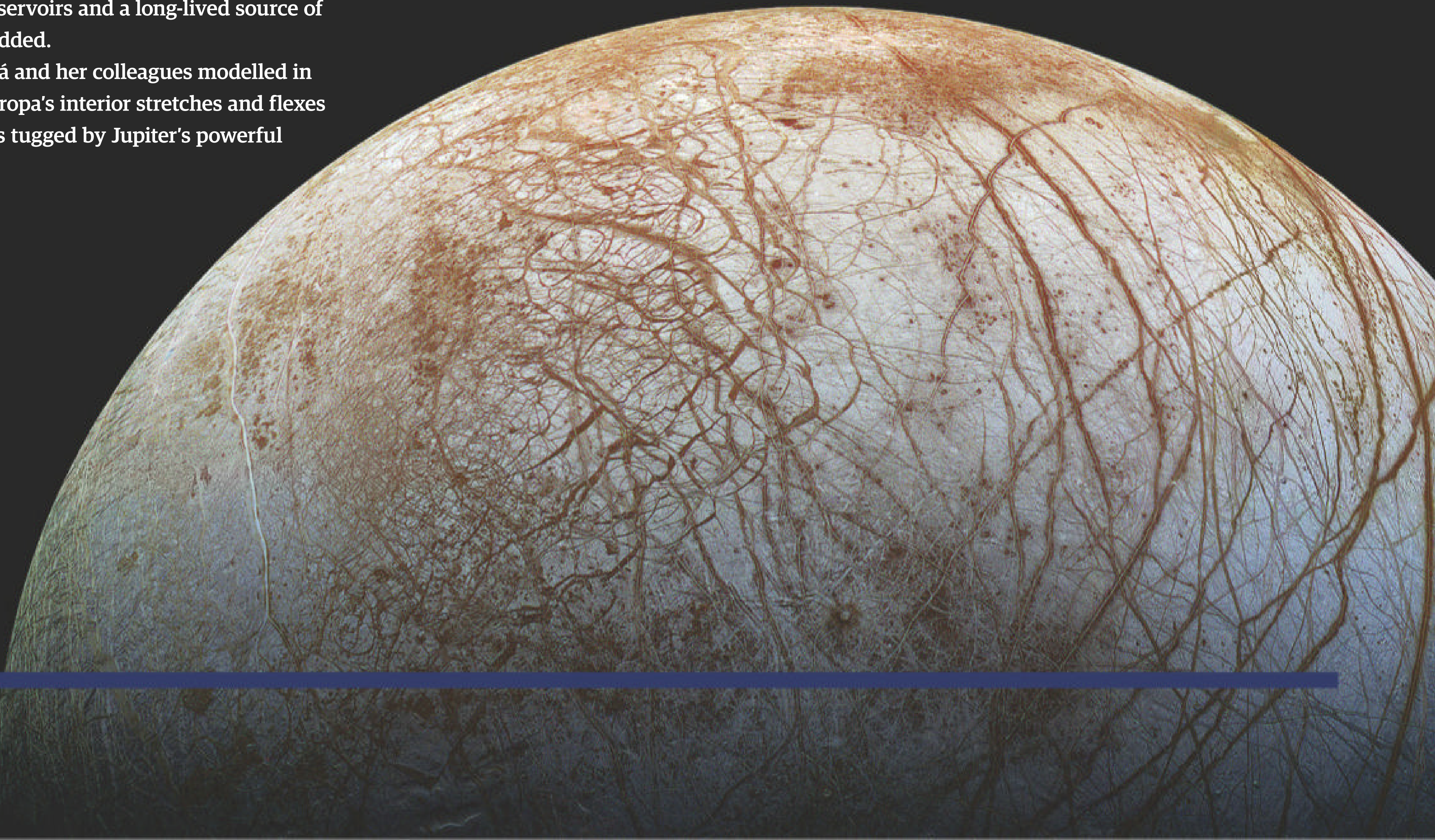
"Our findings provide additional evidence that Europa's subsurface ocean may be an environment suitable for the emergence of life," said Marie Běhounková of Charles University in the Czech Republic. "Europa is one of the rare planetary bodies that might have maintained volcanic activity over billions of years, and possibly the only one beyond Earth that has large water reservoirs and a long-lived source of energy," she added.

Běhounková and her colleagues modelled in detail how Europa's interior stretches and flexes as the moon is tugged by Jupiter's powerful gravity. Such deformation generates frictional heat, which keeps Europa's buried ocean from freezing over - and perhaps even partially melts the upper layer of the moon's rocky mantle.

Such melting may have fuelled seabed volcanoes for most of Europa's history, perhaps even to the present day. Volcanic activity is most likely near Europa's poles, where the internal heat loads are most intense.

Volcanoes on a Jovian satellite would not be unprecedented. One of Europa's fellow Galilean moons, Io, is the most volcanically active body in the Solar System, and its eruptions are fuelled by the same type of gravitational tugging that Europa experiences. In a decade or so, researchers should be able to test and supplement such Europa modelling work with a wealth of new data thanks to NASA's planned Europa Clipper mission.

Clipper is scheduled to launch in 2024 and arrive in orbit around Jupiter in 2030. The probe will then make about 50 close flybys of Europa over four Earth years, characterising the moon's subsurface ocean, studying its icy shell and scouting out good touchdown sites for a future life-hunting lander, among other tasks.



Right: Volcanic vents could be a hotbed for life

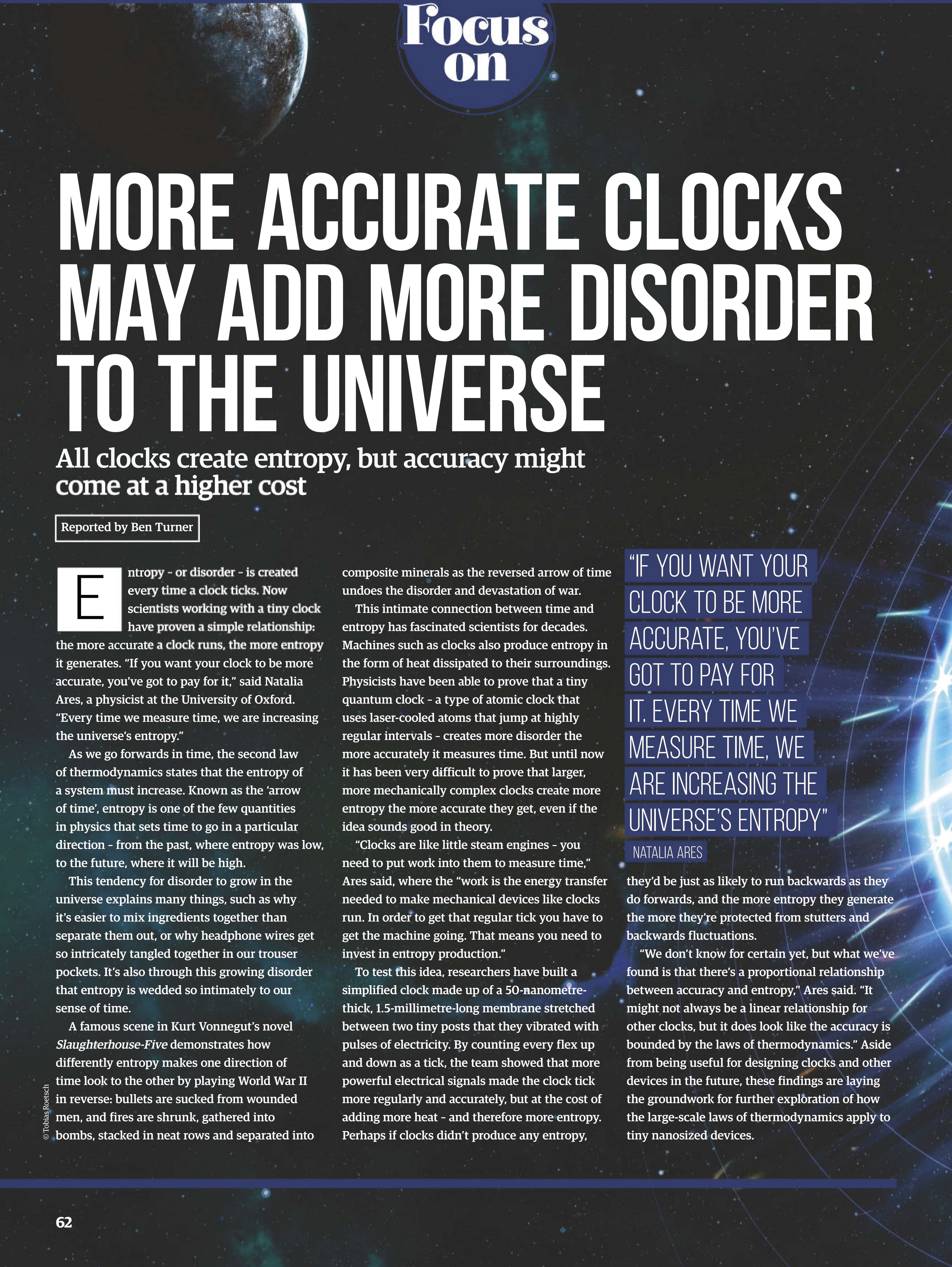
© NASA / JPL Caltech

SUBSCRIBE TODAY

Find your next great read

Subscribe today and get instant access on your iPad, iPhone or Android device. Additional print options available.

http://bit.ly/AASTech21



MORE ACCURATE CLOCKS MAY ADD MORE DISORDER TO THE UNIVERSE

All clocks create entropy, but accuracy might come at a higher cost

Reported by Ben Turner

Entropy – or disorder – is created every time a clock ticks. Now scientists working with a tiny clock have proven a simple relationship: the more accurate a clock runs, the more entropy it generates. "If you want your clock to be more accurate, you've got to pay for it," said Natalia Ares, a physicist at the University of Oxford. "Every time we measure time, we are increasing the universe's entropy."

As we go forwards in time, the second law of thermodynamics states that the entropy of a system must increase. Known as the 'arrow of time', entropy is one of the few quantities in physics that sets time to go in a particular direction – from the past, where entropy was low, to the future, where it will be high.

This tendency for disorder to grow in the universe explains many things, such as why it's easier to mix ingredients together than separate them out, or why headphone wires get so intricately tangled together in our trouser pockets. It's also through this growing disorder that entropy is wedded so intimately to our sense of time.

A famous scene in Kurt Vonnegut's novel *Slaughterhouse-Five* demonstrates how differently entropy makes one direction of time look to the other by playing World War II in reverse: bullets are sucked from wounded men, and fires are shrunk, gathered into bombs, stacked in neat rows and separated into composite minerals as the reversed arrow of time undoes the disorder and devastation of war.

This intimate connection between time and entropy has fascinated scientists for decades. Machines such as clocks also produce entropy in the form of heat dissipated to their surroundings. Physicists have been able to prove that a tiny quantum clock – a type of atomic clock that uses laser-cooled atoms that jump at highly regular intervals – creates more disorder the more accurately it measures time. But until now it has been very difficult to prove that larger, more mechanically complex clocks create more entropy the more accurate they get, even if the idea sounds good in theory.

"Clocks are like little steam engines – you need to put work into them to measure time," Ares said, where the "work is the energy transfer needed to make mechanical devices like clocks run. In order to get that regular tick you have to get the machine going. That means you need to invest in entropy production."

To test this idea, researchers have built a simplified clock made up of a 50-nanometre-thick, 1.5-millimetre-long membrane stretched between two tiny posts that they vibrated with pulses of electricity. By counting every flex up and down as a tick, the team showed that more powerful electrical signals made the clock tick more regularly and accurately, but at the cost of adding more heat – and therefore more entropy. Perhaps if clocks didn't produce any entropy, they'd be just as likely to run backwards as they do forwards, and the more entropy they generate the more they're protected from stutters and backwards fluctuations.

> "IF YOU WANT YOUR CLOCK TO BE MORE ACCURATE, YOU'VE GOT TO PAY FOR IT. EVERY TIME WE MEASURE TIME, WE ARE INCREASING THE UNIVERSE'S ENTROPY"
>
> NATALIA ARES

"We don't know for certain yet, but what we've found is that there's a proportional relationship between accuracy and entropy," Ares said. "It might not always be a linear relationship for other clocks, but it does look like the accuracy is bounded by the laws of thermodynamics." Aside from being useful for designing clocks and other devices in the future, these findings are laying the groundwork for further exploration of how the large-scale laws of thermodynamics apply to tiny nanosized devices.

© Tobias Roetsch

Above: Every clock in the universe creates entropy as it ticks away

STAR PROFILE

MIRA

This variable star is the queen of hide and seek

From one of the brightest stars in the entire sky to one of the dimmest, Mira's dazzling qualities have been fascinating scientists for centuries. Located 350 light years away in the constellation of Cetus (the Whale), Mira - officially designated Omicron Ceti - lies on the celestial equator, and can therefore be seen from the entire Earth, but only when it is visible, which is not very often.

This intriguing celestial object is an intrinsic variable star, meaning it differs in brightness, and this variety is caused by the fundamental structure of the star. Mira's brightness fluctuates on a regular schedule, with a peak in luminosity roughly every 11 months. At its dimmest, Mira is a tenth-magnitude star barely visible with a modest set of binoculars. However, during its brighter phase, peaking around magnitude +3.5, no equipment is necessary, as Mira can be observed with the naked eye.

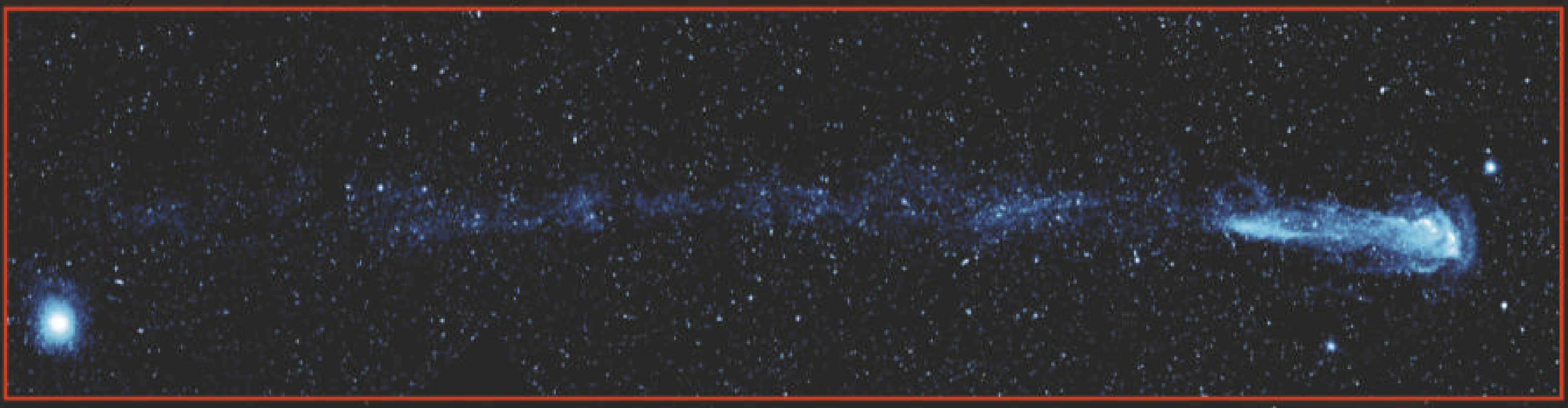
These notable fluctuations in Mira's brightness date back as far as at least the 16th century. Mira was the first variable star to be discovered when David Fabricius, a German pastor and amateur astronomer, noted a third-magnitude star in Cetus in August 1596. Within just a few weeks of his observations, the star had increased in brightness by a full order of magnitude. This light show was short-lived, however, as just two months after Fabricius had observed the star, it had disappeared from view.

In 1638 Dutch astronomer Johannes Holwarda kept an eye on the peculiar star, noticing that it brightened and dimmed over an 11-month period. In 1662 the star was named Mira by German-Polish astronomer Johannes Hevelius, after the Latin word for wonderful - though it wasn't until 2016 when the name was officially approved by the International Astronomical Union's (IAU) Working Group on Star Names (WGSN). Other variable stars that have pulsation periods ranging from 180 to 1,000 days are known as Mira-type variables. They are usually cooled red giants with temperatures around 2,726 degrees Celsius (4,938 degrees Fahrenheit).

Scientists are interested in Mira as it is a red giant, a celestial object our own Sun will turn into some 5 billion years from now. Red giants evolve from main-sequence stars that have masses in the range of 0.3 to approximately eight solar masses. Though past its prime, this wonderful stellar furnace has not quite finished with its dynamic light show. Mira has exhausted most of its hydrogen fuel, and as it throws off its outside layers the star appears to pulsate, a process thought to cause the variability in the star's brightness. Once this red giant has run out of fuel it will turn into a white dwarf, shrouded in a shell of gas known as a planetary nebula.

> "NOTABLE FLUCTUATIONS IN MIRA'S BRIGHTNESS DATE BACK AS FAR AS AT LEAST THE 16TH CENTURY"

Below: In 2007 the GALEX ultraviolet satellite revealed this impressive bow shock, and a tail about 13 light years long, caused by Mira speeding through the Milky Way



© NASA/JPL-Caltech

Below: Mira is expelling its outer layers as it exhausts its hydrogen fuel

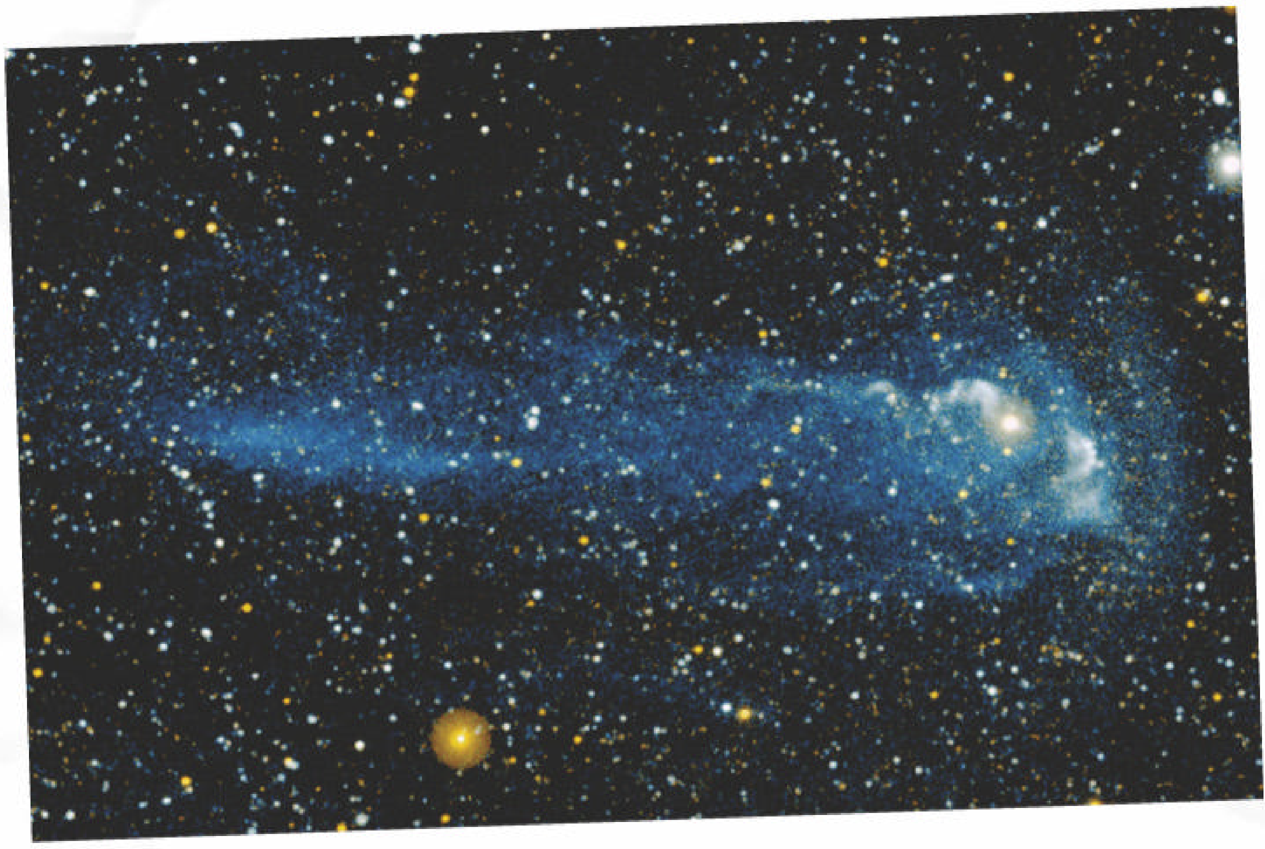
© Getty

NEWS FROM MIRA

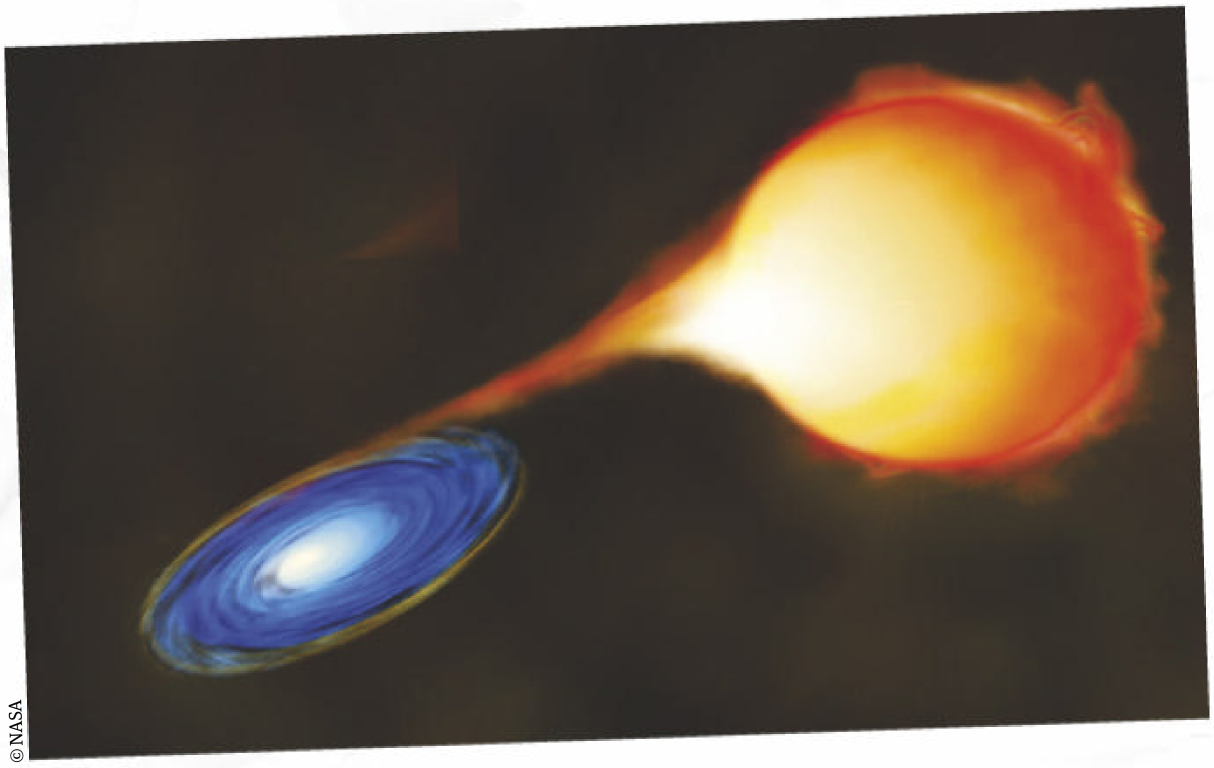
A wonderful shooting star

During a routine survey of the night sky in 2007, NASA's Galaxy Evolution Explorer (GALEX) satellite spotted a 13 light year-long tail streaming out from behind Mira as it hurtled through the Milky Way. It was the first time anything like this had been observed around a star, and the impressive tail is only visible in the far-ultraviolet. The tail helps to shed light on the history of Mira, as the oldest material would have been released from Mira over 30,000 years ago.

Mira is currently ejecting the equivalent of Earth's mass every ten years. It's possible that the tail used to be longer, and has since faded with time so we can no longer detect it, or the star could have shifted into an area of the interstellar medium that is denser, making the tail light up more. Currently this stellar wonder is tearing through the Milky Way at speeds of 130 kilometres (80 miles) per second – over 300 times the speed of a bullet on Earth. The bow shock at the front of the star is formed from a build-up of gas as it hurtles through the galaxy – similar to water accumulating at the front of a fast boat.



© NASA, JPL-Caltech



© NASA

Two for the price of one: the Omicron Ceti system (Mira AB)

Remarkably, Mira is not alone. The variable star is one of two stars in a symbiotic system, where it is joined by a white dwarf, VZ Ceti, also known as Mira B. Mira B is much dimmer and smaller than its companion red giant Mira, and is estimated to be 3,300 times as dense as our Sun. Mira AB is the closest symbiotic binary system to our Sun. The dwarf star was first suggested to exist by Alfred Joy of the Mount Wilson Observatory, California, but it wasn't visually confirmed until Robert Aitken of the Lick Observatory in California observed the star with a 36-inch refractor in 1923.

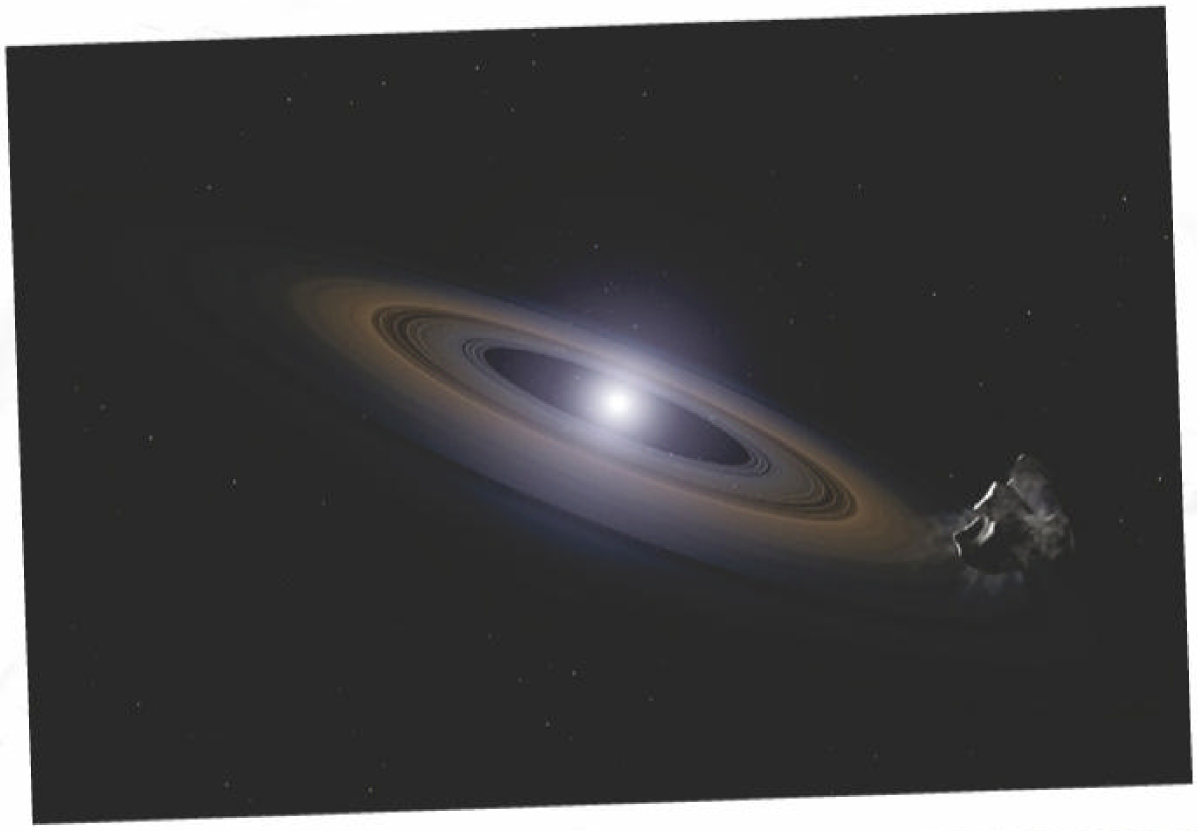
This plucky white dwarf has been siphoning off material from the pulsating red giant, and completes an orbit of Mira every 497.88 years. The two stars are currently separated by about 10.5 billion kilometres (6.5 billion miles), and despite their entwined relationship, astronomers believe that Mira B has no effect on the impressive tail spewed out by Mira.

Old stars making way for the new

In 2007, the first planet-forming disc was discovered around a dying star. Prior to this discovery, such discs were generally assumed to be found around young stars in stellar nurseries. Using observations from the Keck I telescope in Hawaii and the Gemini South telescope in Chile, scientists have found about one per cent of the material thrown off from Mira A is captured in a disc around Mira B. If Mira A were a single star, all of this material would simply be lost to space.

In approximately 1 million years when Mira A has finished with its stellar outburst, having run out of material, the disc formation around Mira B will cease. This abundance of material could then fuel the production of new planets, therefore giving rise to an unusual scenario where ageing stars are laying the foundations for the next generation of celestial objects.

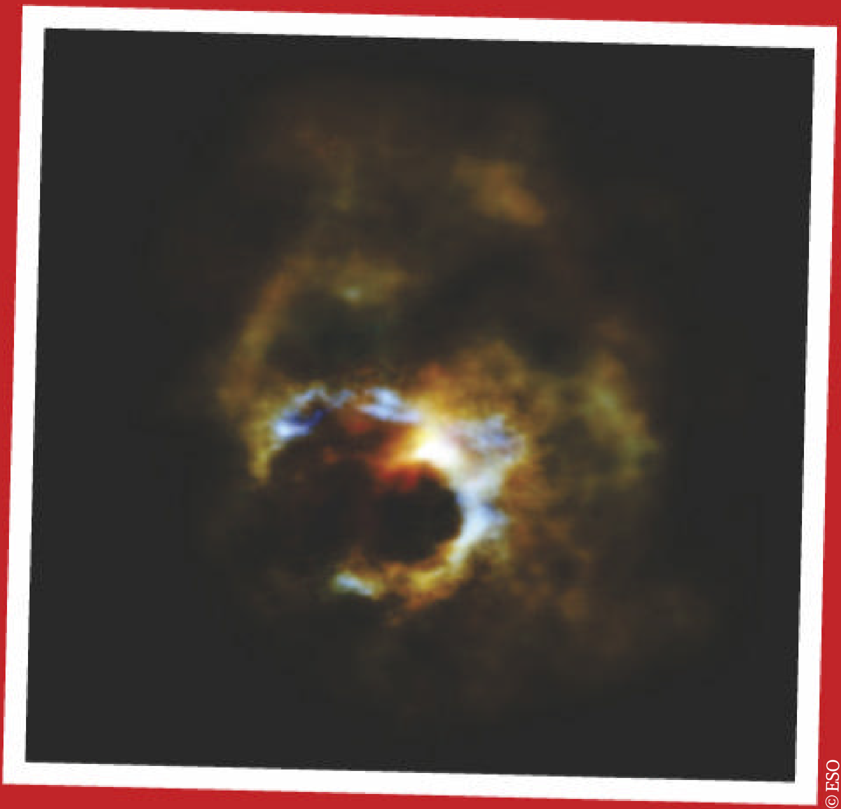
Usually the death of a star is accompanied by the death of its planetary system. This discovery has led scientists to consider even more possible locations to look for young planets orbiting stars other than our Sun.



© NASA, ESA

ALMA SHEDS LIGHT ON THE COMPLEXITY OF THE MIRA AB SYSTEM

In 2014 an image captured by the Atacama Large Millimeter/submillimeter Array (ALMA) radio telescope revealed how the stellar winds from both Mira A and B have created a stunningly complex nebula. While Mira A has a slow wind, gently moulding the surrounding material, ALMA has revealed that Mira B approaches things very differently. The hot, dense white dwarf exhibits a ferocious stellar wind which has created the heart-shaped bubble in the centre of the ALMA image. The heart is thought to have formed approximately 400 years ago, and is caused by Mira B's speedy stellar winds churning up material in the centre, blowing a bubble in stellar material which expands the surrounding gas.



© ESO

Above: This image was captured by a radio telescope in Chile and shows the gas around the stars

> "THIS PLUCKY WHITE DWARF HAS BEEN SIPHONING OFF MATERIAL FROM THE PULSATING RED GIANT, AND COMPLETES AN ORBIT OF MIRA EVERY 497.88 YEARS"

MIRA BY NUMBERS

11 MONTHS
The length of Mira's variable light cycle

350 LIGHT YEARS
The distance Mira is from Earth

80 MILES PER SECOND
The speed at which Mira is hurtling through our galactic home

13 LIGHT YEARS
The length of Mira's tail as it streaks through the Milky Way

6 BILLION YEARS
The estimated age of Mira

1.18 SOLAR MASSES
The mass of Mira

400-500
How many times larger Mira's diameter is compared to our Sun's

FORMATION OF MIRA AND NOTABLE DISCOVERIES

- **Date:** Approximately 6 billion years ago
  Activity: Mira formed.
- **Date:** August 1596
  Activity: Mira was discovered by German pastor and amateur astronomer David Fabricius.
- **Date:** 1638
  Activity: Dutch astronomer Johannes Holwarda noticed that Mira brightened and dimmed considerably over an 11-month period.
- **Date:** 1662
  Activity: German-Polish astronomer Johannes Hevelius named the variable star Mira.
- **Date:** 1923
  Activity: Mira's white dwarf companion Mira B is confirmed by Robert Aitken of the Lick Observatory in California.
- **Date:** 2007
  Activity: NASA's Galaxy Evolution Explorer (GALEX) captured the striking image of Mira's tail.
- **Date:** 2014
  Activity: An image captured by the Atacama Large Millimeter/submillimeter Array radio telescope (ALMA) reveals fierce stellar winds from Mira B.
- **Date:** 2016
  Activity: Mira's name is officially approved by the International Astronomical Union (IAU).

© ESO

MYSTERIES OF THE UNIVERSE

ARE EXOPLANETS SHRINKING WITH AGE?

© Tobias Roetsch

ASTRONOMERS MAY BE CLOSER THAN EVER TO KNOWING WHY SUPER-EARTH EXOPLANETS ARE SO SCARCE

Reported by David Crookes

As we all know, planets come in many different sizes, and you only have to look at our Solar System to see how varied they can be. Just take Mercury as the smallest, for example, and Jupiter as the most humongous. If you had enough Mercurys at your disposal, you could take 24,462 of them and pack them tightly into Jupiter. For comparison, you could do the same with 1,300 Earths.

Interestingly, though, there is a size gap. Try as you may, you're not going to find too many planets anywhere in the universe that are between 1.5 and two times the size of Earth. You certainly won't find them in our Solar System and, so far at least, there are very few in planetary systems elsewhere, suggesting there's no middle ground between so-called rocky super-Earths and larger gas-shrouded mini-Neptunes. Quite why, however, has been a mystery.

Such a gap was not apparent at first, certainly not when scientists began discovering planets outside of our Solar System from 1992. Back then the first extrasolar planet, or exoplanet, was found when astronomers Aleksander Wolszczan and Dale Frail provided evidence of two planets orbiting a pulsar some 2,300 light years away. But they were large and easily spotted. It's only when technology grew more sophisticated that smaller exoplanets began being discovered, and the gap became rather stark.

To underline just how recent a mystery this is, a planet 1.4 times the size of Earth, Kepler-10b, was only discovered by the now-deactivated Kepler space telescope in January 2011. Even so, it took until 2017 for the gap's existence to be reported as more and more exoplanets were confirmed – there have been more than 4,400 discovered to date. That was the year a study headed by Benjamin J. Fulton emerged, which is why the observation is often referred to as the Fulton gap.

Since this gap became apparent, there has been a great deal of academic detective work to try and discover what could be the best explanation for why planets orbiting close to their star are either small or large, with very few in between. Further findings by the Transiting Exoplanet Survey Satellite (TESS), which launched in 2018, have only added further weight, encouraging scientists to press on.

"The gap in planet sizes has prompted research simply because it was unexpected and because it is still unexplained," says Trevor David, a research fellow at the Flatiron Institute's Center for Computational Astrophysics in New York City. "The gap is statistically significant, and it's not the result of any observational bias, so the exoplanet community generally believes this is a real feature in the data that requires an explanation.

"For many natural processes, there often exists a spectrum of possible outcomes, so when we see something that is so clearly bimodal – almost binary outcomes in the sense that a planet either resides above or below this gap – it immediately catches the interest of scientists. Why are so few planets found in the gap? And are planets below or above the gap different in ways other than their sizes?"

TAP HERE TO PLAY

Left: TESS is surveying 200,000 of the brightest stars near our Sun in the search for transiting exoplanets. It's unlikely to find many that fall within the small planet radius gap

EXOPLANETS BY NUMBERS

4,422
Number of exoplanets confirmed as of 25 June 2021

7,445
Number of exoplanet candidates as of 25 June 2021

1,356
Number of super-Earths confirmed

1,496
Number of exoplanets that are Neptune-like

1917
When exoplanets were first unknowingly located

1992
Year a super-Earth was first found

2009
When NASA's Kepler spacecraft was launched

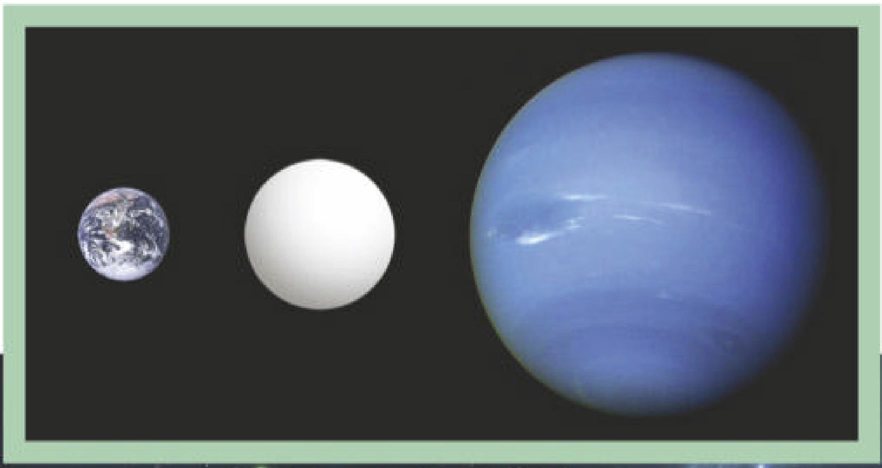
2018
When work was taken up by TESS

22%
Sun-like stars with Earth-sized planets in their habitable zones

SIX
Distance of a dim, frozen super-Earth in light years

Below (top): Here you can see the difference between the size of Earth (left), the super-Earth CoRoT-7b (centre) and Neptune (right). CoRoT-7b just falls within the gap at 1.68 times Earth's radius

Below: Super-Earth planets seem to be a cosmic rarity



© NASA

To help resolve such questions, David and his team selected 700 exoplanets that were less than ten times the size of Earth. These were taken from the California-Kepler Survey, which measures the precise properties of planets and their host stars using data from NASA's Kepler mission.

"The size of a transiting planet is measured relative to its host star's size," David tells **All About Space**. "Once the stellar sizes were determined with sufficient precision, it became clear that the planet size distribution was multimodal - that it had many peaks. Researchers had previously detected the planet signals and measured the planet-to-star size ratios. But the radius gap was essentially 'blurred' out due to inaccurate and/or imprecise stellar radii."

The 'twist' in the research carried out by David and his team was that they looked to determine the age of the exoplanets they selected. They wanted to see if the ageing of planets had any bearing on whether or not the radius gap changed by making those rare sizes more common, and their study became the first to show that the precise location of the gap shifts with the age of the planetary systems being studied.

But how did they do this? First of all, ageing the exoplanets can be done using a combination of their chemical composition, brightness, colour and distance. Based on the premise that planets form around the same time as their host stars, the researchers were then able to place the exoplanets into two distinct categories: those that were older than 2 billion years, and those that were aged at less than 2 billion years.

"I was primarily motivated by the observation that the youngest transiting planets appear to be unusually large," David explains. "This motivated me to understand how long this phase of apparent inflation may last, and whether planet sizes continue to evolve over longer timescales."

The study suggested that the least common planet radii from the younger set was 1.6 times Earth's radius and that this was smaller, on average, than the least common radii from the older set - some 1.8 times Earth's radius.

"Just a few months prior to our research, there were two other studies that appeared to show that the overall distribution of planet sizes evolves over billions of years," says David. "Those studies looked at a single metric: the number of super-Earth detections relative to the number of mini-Neptune detections. It appears that super-Earths are more common, relative to their mini-Neptune counterparts, at older ages. One way to explain this observation is if some mini-Neptunes are converted into super-Earths over time, where that timescale happens to be billions of years."

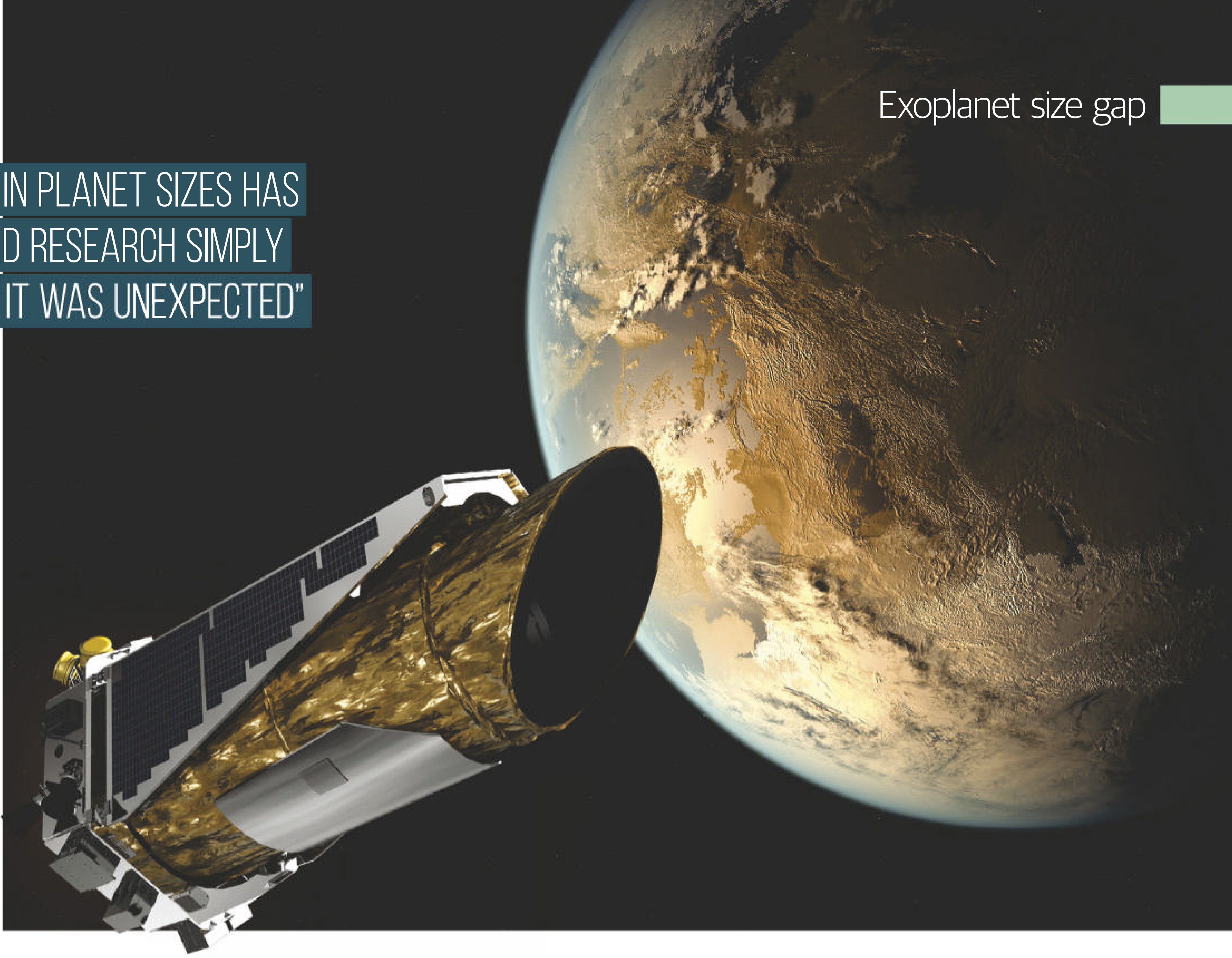
In other words, the larger mini-Neptunes appear to be shrinking down to their rocky cores as they

© Getty

> “THE GAP IN PLANET SIZES HAS PROMPTED RESEARCH SIMPLY BECAUSE IT WAS UNEXPECTED”
>
> TREVOR DAVID

Right: The Kepler space telescope launched in 2009 to discover Earth-sized planets orbiting other stars

Below: David has headed important research into the rarity of planets that are between 1.5 and two times the size of Earth



© NASA; Getty

get older – an example of atmospheric loss which has previously been put forward as an explanation for the gap. Crucially, given there were very few mid-sized planets in the younger group and more in the older one, it suggested rare sizes of planets become more common over time.

By shrinking, the study found that mini-Neptunes could be leaping over the planet radius gap to become super-Earths. Over time this will involve ever-larger mini-Neptunes making the leap as they transform into larger super-Earths.

“For some, and perhaps most mini-Neptunes that conversion may occur quickly [within the first billion years], but for other planets it appears that their evolution proceeds slowly,” says David. “What I chose to focus on was not how the relative number of super-Earths and mini-Neptunes changed over time, but rather whether the gap in the planet size distribution shifts with time or remains fixed at all ages.”

One of the questions which could emerge around a study such as this is why – if indeed mini-Neptunes reduce in size because their atmospheres are leaking away to leave behind a solid core – this only seems to happen rapidly with the smaller ones. The explanation is that mini-Neptunes with enough mass can retain their atmospheres thanks to gravity, but the smaller mini-Neptunes can’t hold on to their gas, meaning they’ll shed quickly. The astronomers say the gap is the “chasm between the largest size super-Earths and the smallest size mini-Neptunes”. And that gap evolves over billions of years.

Indeed, as David explains: “Theoretical models predict that the super-Earth population fills in from the ‘bottom up’.” If super-Earths are formed from atmospheric loss, then we expect the smallest and least massive cores to lose atmospheres first. “Over time, larger and larger planetary cores lose their atmospheres and fill out the super-Earth population we observe today,” David says.

But what are they shrinking from and to, in terms of size? It’s hard to pinpoint exactly because planets form with a range of core masses, atmospheric masses and separations from their host stars. Some planets may never lose their atmospheres entirely, while others can become completely stripped, David explains.

“The largest super-Earths are around 1.8 Earth radii, but the average super-Earth size is closer to 1.3 Earth radii,” he continues. “The average mini-Neptune size is about 2.4 Earth radii, so if a super-Earth started off with a sizable atmosphere, it could have been anywhere between two and ten Earth radii in the past, depending on its specific evolutionary history and how far back in time you went.

“We don’t know very well how large planets are at the beginning of their lives, but the few examples of extremely young transiting planets that we do know of are unusually large. Some of those young planets are between five and ten times the size of Earth, but finding planets of those sizes at older ages is a rare occurrence.”

But what is causing the planets to lose their atmospheres? As you may expect, this isn’t clear, but there are a number of theories. One is that heat left over from planetary formation will transfer energy into the planet’s atmosphere. The gas then escapes into space, and the exoplanet shrinks.

“We believe that planets are assembled from collisions of ever-larger rocky bodies,” says David. These collisions deposit a large amount of energy into the growing planet’s core, so much so that the core may be totally molten early on. “Over time the core cools and contracts, and the energy radiated away from the core must go somewhere. That energy is deposited into the atmosphere, and if the energy transferred becomes comparable to the binding energy of the atmosphere, then an outflow will launch atmospheric gas away from the planet.”

Another theory has much the same effect, again allowing gas to escape. “It says high-energy radiation [specifically X-ray and ultraviolet radiation] from

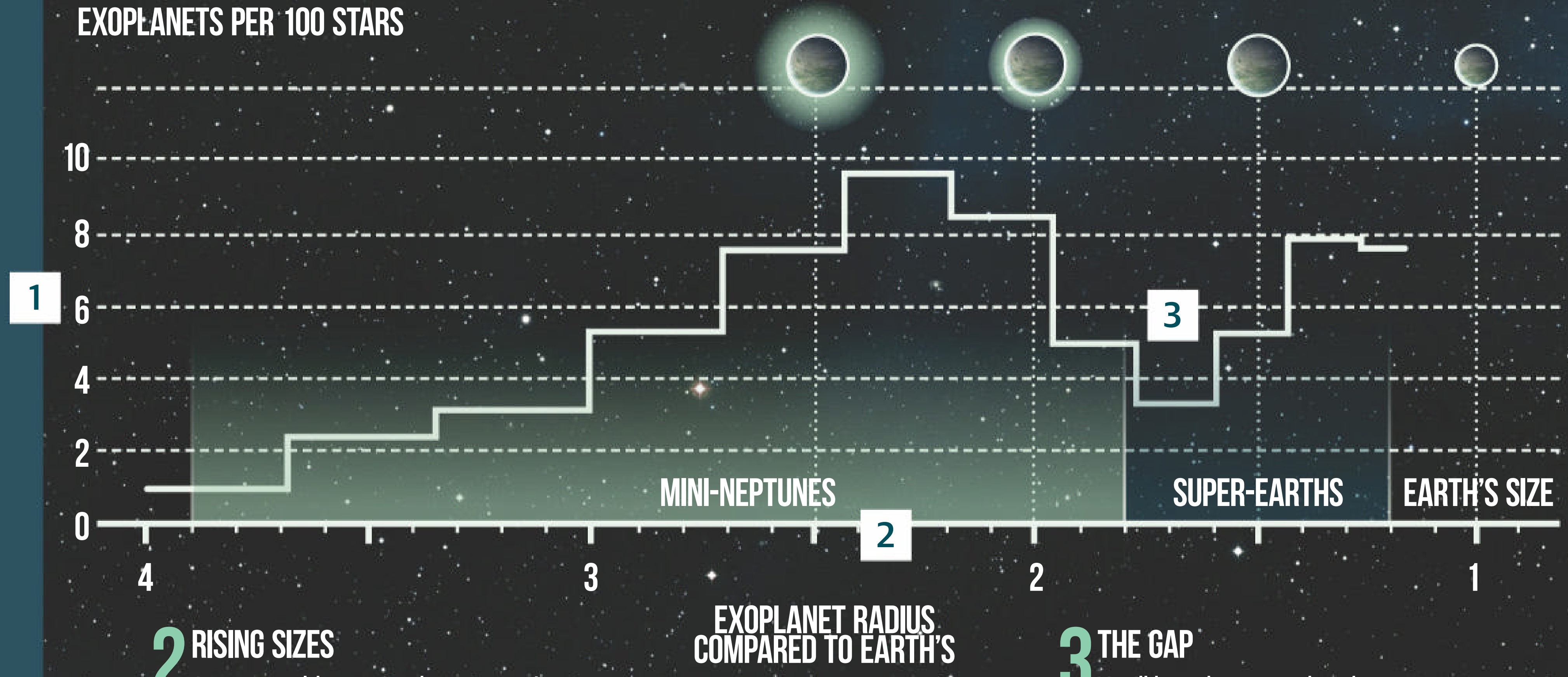
© Simons Foundation

MINDING THE GAP

Scientists have known since 2017 that there is a gap in the discovery of exoplanets

1 AN INCREASE IN NUMBERS

Astronomers have found thousands of exoplanets since 1992, and it stands to reason that they are able to discover them more easily when they are larger, hence the greater number of gas giants.



2 RISING SIZES

As you would expect, when comparing other planets to the radius of Earth, super-Earths – by nature of their name – are going to be larger than our planet, and mini-Neptunes are going to be larger still.

3 THE GAP

You'll hear, however, that there are relatively few discoveries of exoplanets that are between 1.5 and two times Earth's radius. It is this gap that scientists have sought to explain.

4 OLD AND YOUNG

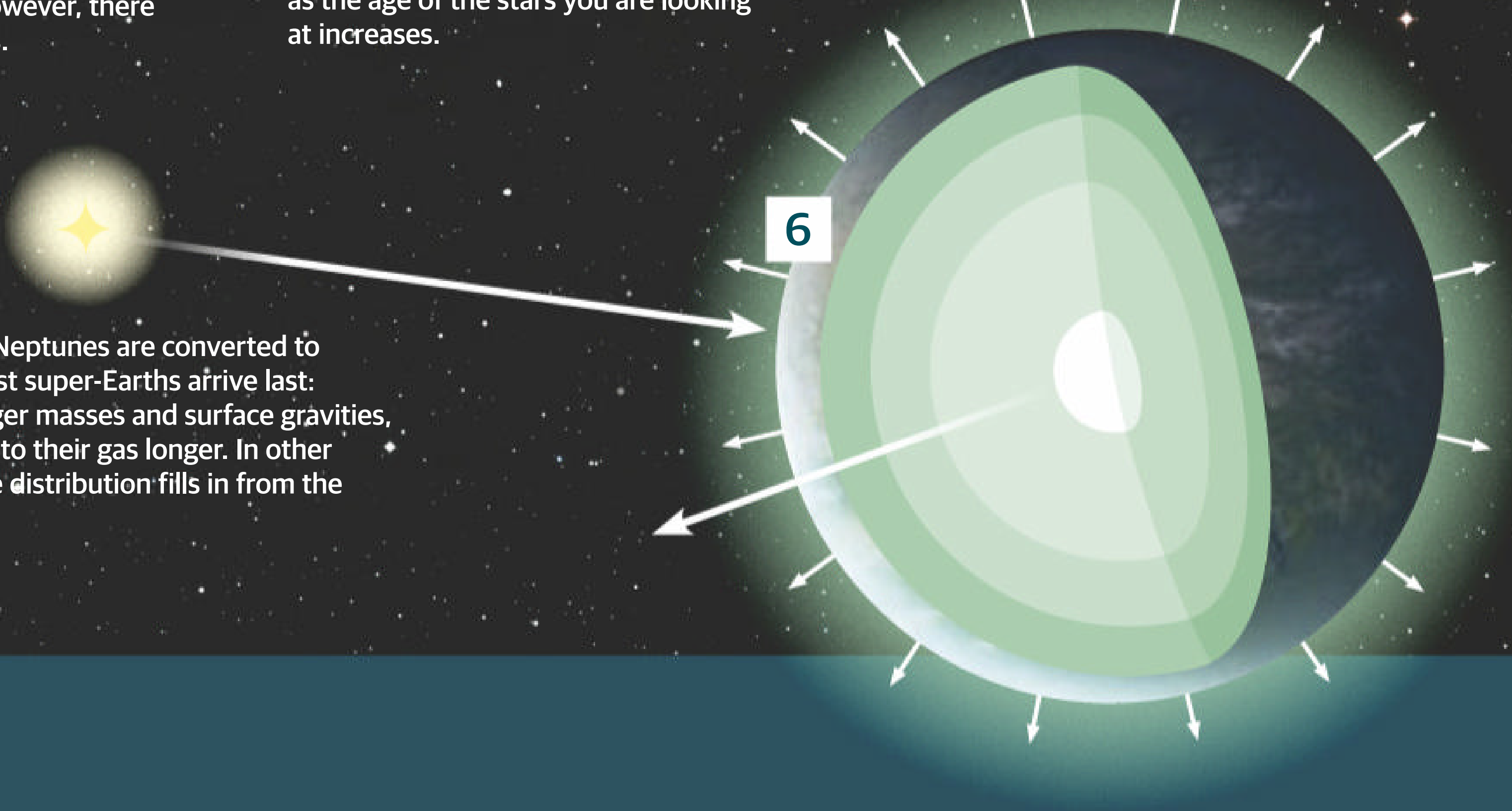
The largest observed super-Earth planets – those between 1.6 and 1.8 Earth radii – don't seem to be found around younger stars. They are, however, there when looking at older stars.

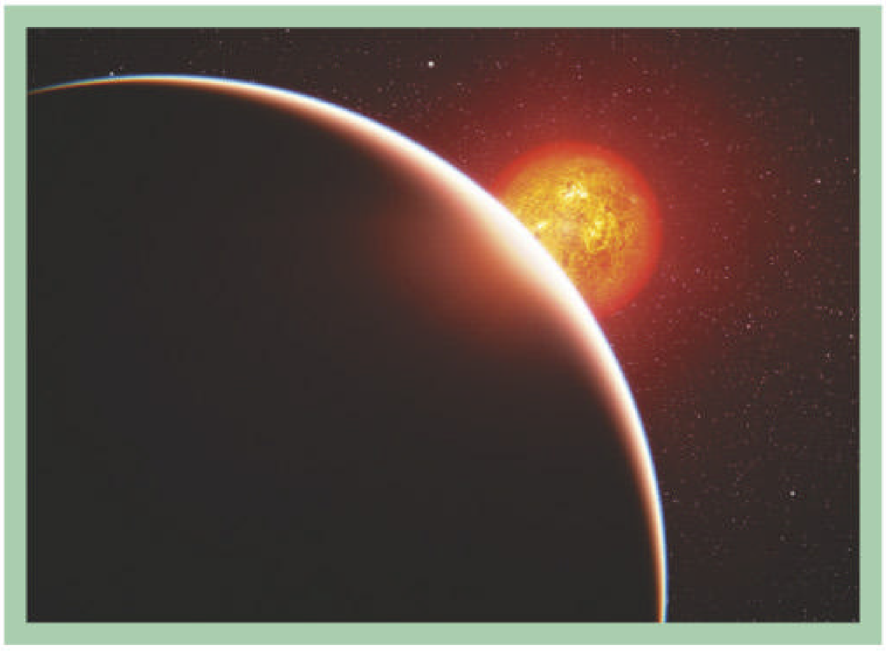
5 LOSING GAS

It appears that the number of super-Earth detections, relative to the number of mini-Neptune detections, increases as the age of the stars you are looking at increases.

6 GETTING SMALLER

David says some mini-Neptunes are converted to super-Earths, but the largest super-Earths arrive last: "Presumably they have larger masses and surface gravities, so they are able to hold on to their gas longer. In other words, the super-Earth size distribution fills in from the bottom up," he explains.





© ESO

the host star heats the upper layers of a planet's atmosphere. The heat provided by the high-energy stellar radiation can be enough to drive an 'outflow' of gas from the planet. Depending on how substantial and how prolonged this mass loss is, a planet can become partially or totally stripped of its atmosphere," David says.

If planets are losing their atmospheres and becoming smaller over time, however, why don't many more stick around in the gap? "In some analyses the gap appears to be completely empty - totally devoid of planets. In other analyses of generally less precise data, the gap appears to be sparsely populated, but not completely empty.

"In my view the community hasn't conclusively answered whether planets can exist in this gap because there are so many factors that can cause an observer to inaccurately infer a planet's size, even with very precise data in hand," David answers. "Some studies have invoked exotic compositions such as water worlds to explain the apparent presence of planets in the gap. But many observations of the exoplanets found with Kepler can be explained with a single population of exoplanets that are born with rocky cores and gaseous envelopes dominated by hydrogen and helium. Some of these planets retain their primordial atmospheres, while others lose them. This would be the simplest explanation for many observations made regarding Kepler-type planets."

There's clearly more work to be done, and research will be ongoing, yet we're getting a clearer picture of how planets evolve. "Our study suggests that, for some planets, evolution in something as basic as a planet's size may continue for billions of years," David says. "I didn't expect to see such slow evolution, nor was I expecting the radius gap to move as a function of age in the data we were looking at."

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

Above: Gliese 1214 b is a mini-Neptune that could well be shrinking into a super-Earth

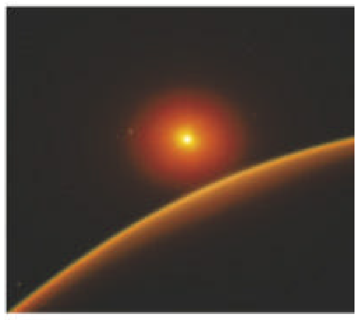
Below: The pulse of PSR B1257+12 was studied using the Arecibo radio telescope in Puerto Rico in 1992, with regular offbeats pointing to the first confirmed exoplanets

THE THEORIES

What could be causing mini-Neptunes to lose their atmospheres?

EXOPLANETS ARE NOT LOSING THEIR ATMOSPHERES

According to David, this theory suggests that super-Earths are not the product of planets that have lost their atmospheres. Instead the theory explains that they avoided accreting atmospheres to begin with: "In this theory, whether or not a planet becomes a rocky super-Earth or a gaseous mini-Neptune depends on whether or not the core formed early enough to accrete and hold onto a substantial amount of gas."



© ESO

IT'S CAUSED BY HIGH-ENERGY RADIATION

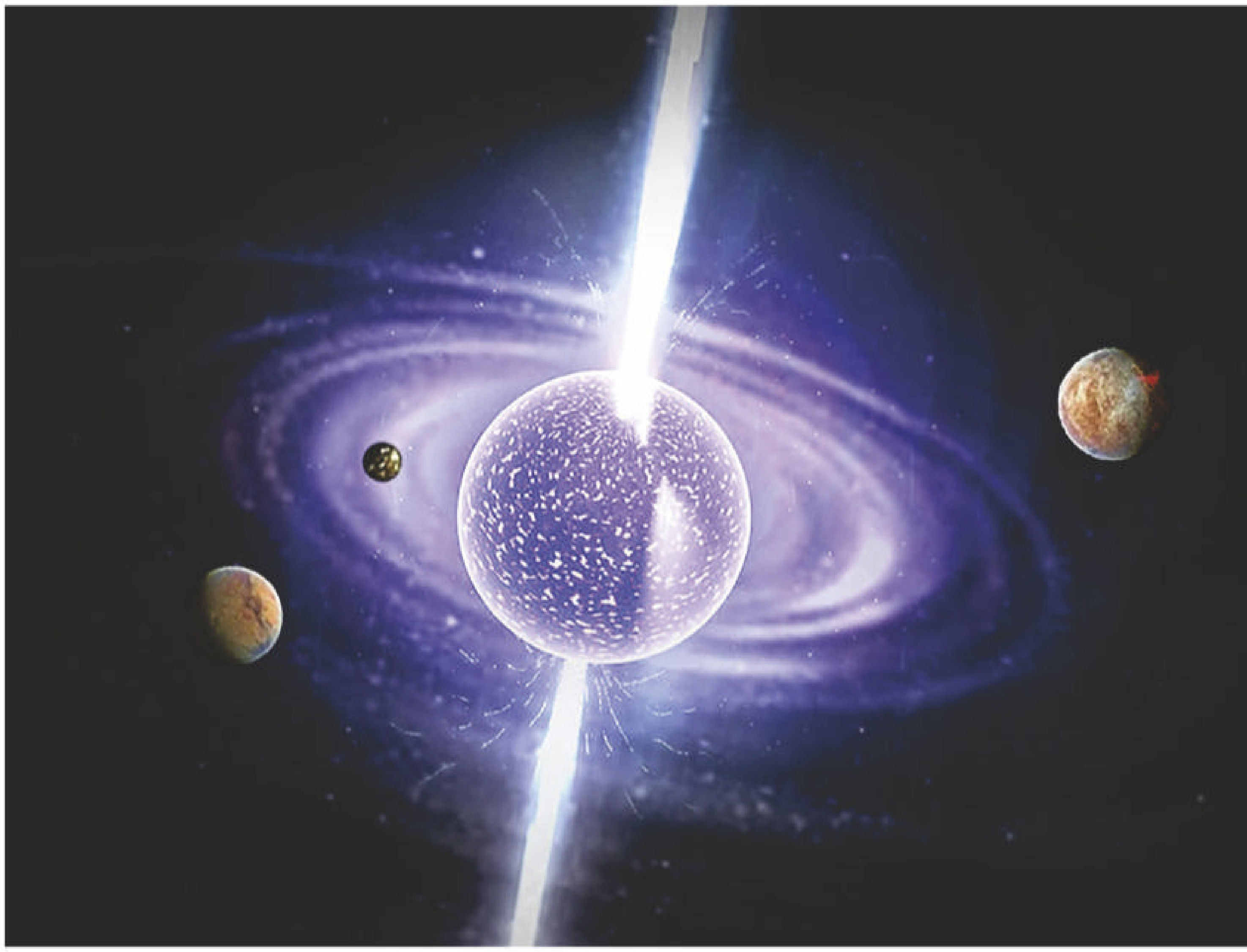
This assumes that the exoplanets have accreted atmospheres. As David says, the accretion will have happened when the gaseous protoplanetary disc was still around - that is, in the first 10 million years. In this theory, X-ray and ultraviolet radiation, due to close proximity with the star, heat away molecules from the planet's upper atmosphere in a process known as photoevaporation. This will take the planet down towards its core. Astronomers think it's a more likely explanation.

© NASA

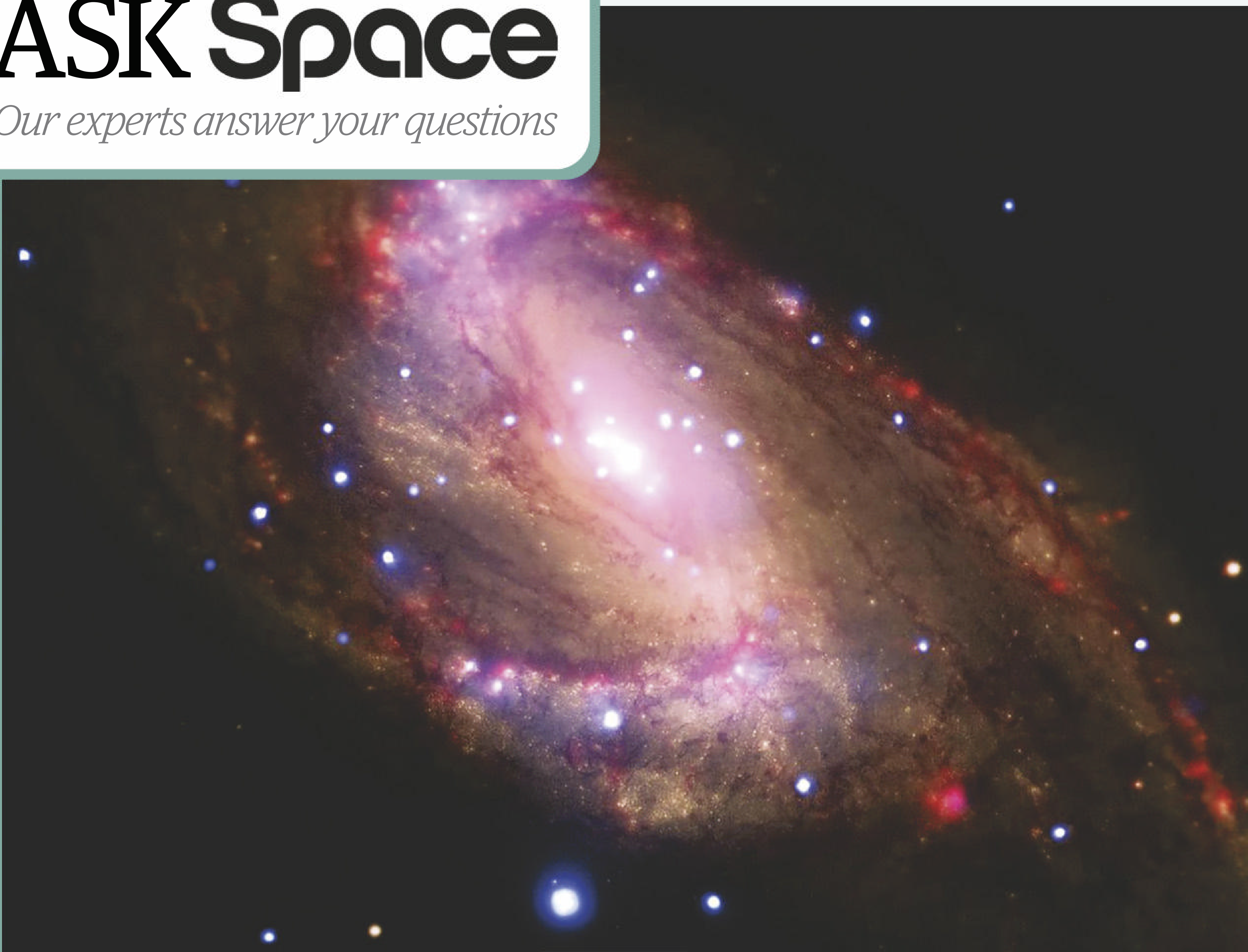
IT'S DUE TO LEFTOVER HEAT FROM AN EXOPLANET'S FORMATION

Remnant heat from a planet's formation caused by collisions with rocky bodies is said to escape the planetary core and transfer to its atmosphere. In a similar process as predicted by the photoevaporation theory, the outflow of energy departs into space. Again this is a leading theory, but there is a fourth, less advanced suggestion that collisions directly cause net atmospheric losses if they are energetic and frequent enough.

© NASA/JPL-Caltech



Source: Wikipedia Commons © Pablo Carlos Budassi



ASTROPHYSICS

Do all galaxies have a black hole at the centre?

It sure seems that way! The centre of every galaxy we've been able to examine in detail has proved to be the host of a supermassive black hole. The most famous recent addition to our understanding is the directly imaged shadow of the supermassive black hole in the centre of Messier 87. At 6 billion times the mass of our Sun, M87's black hole is a tremendously large object. But what of other, more distant galaxies where we can't go look directly?

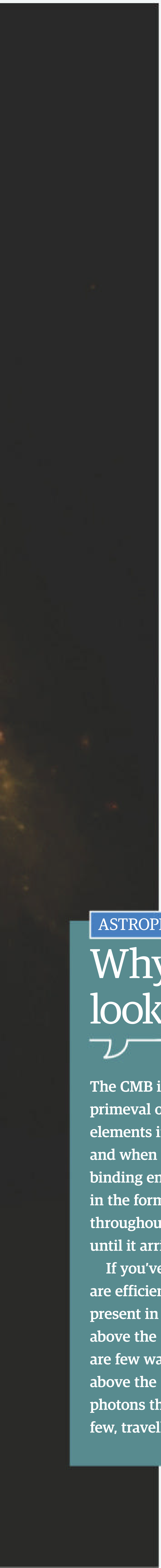
M87 gives us a clue. In addition to being able to see the shadow of the black hole directly, its supermassive black hole also drives a thin jet of gas, larger than the entire galaxy, out from its centre. The energy required to launch material like this is best explained by a black hole, and in M87 we see them together. In more distant galaxies, we can use the presence of energetic jets, or other similar phenomena, to infer the frequent presence of a supermassive black hole - and they are indeed so frequent that we conclude that all massive galaxies should have one.

Dr Jillian M. Scudder, assistant professor at Oberlin College and Conservatory, Ohio

Above: Spiral galaxy NGC 3627 contains a bright X-ray source in the centre that is suggestive of a supermassive black hole

© NASA/JPL-Caltech, ESO

> "THE ENERGY REQUIRED TO LAUNCH MATERIAL LIKE THIS IS BEST EXPLAINED BY A BLACK HOLE"
> JILLIAN M. SCUDDER



© NASA/JPL-Caltech

EXOPLANETS

What are hot Jupiters?

Hot Jupiters are large, gaseous exoplanets of similar size to Jupiter, but with much higher temperatures due to their proximity to their host star. Exoplanets – planets outside our Solar System – are often assigned broad categories depending on their physical characteristics – for example hot Jupiters, sub-Neptunes or super-Earths.

The hot Jupiter class is particularly interesting as it encompasses planets that we don't observe in our Solar System. These planets are large, mainly composed of hydrogen and helium like Jupiter and are located closer to their host stars than Mercury, reaching temperatures of thousands of degrees. A year for those planets is only a matter of hours to days. These properties make them relatively easy to observe, and while they seem to be a rare outcome of planetary formation, many such planets have already been discovered.

As of today their formation remains a mystery, but since understanding how they formed might tell us a lot about the history of our own Solar System, they are prime targets for current and future telescopes. While they could have formed in-situ, many theories suggest that they started forming far from their star and then migrated inwards, sweeping material from the protoplanetary discs they were born in.

Quentin Changeat, postdoctoral research fellow at University College London

Above: Simulated views of ultrahot Jupiter WASP-121b

Below: Cosmic microwave background imaged by the ESA's Planck mission

ASTROPHYSICS

Why are conditions in Antarctica ideal for looking at the cosmic microwave background?

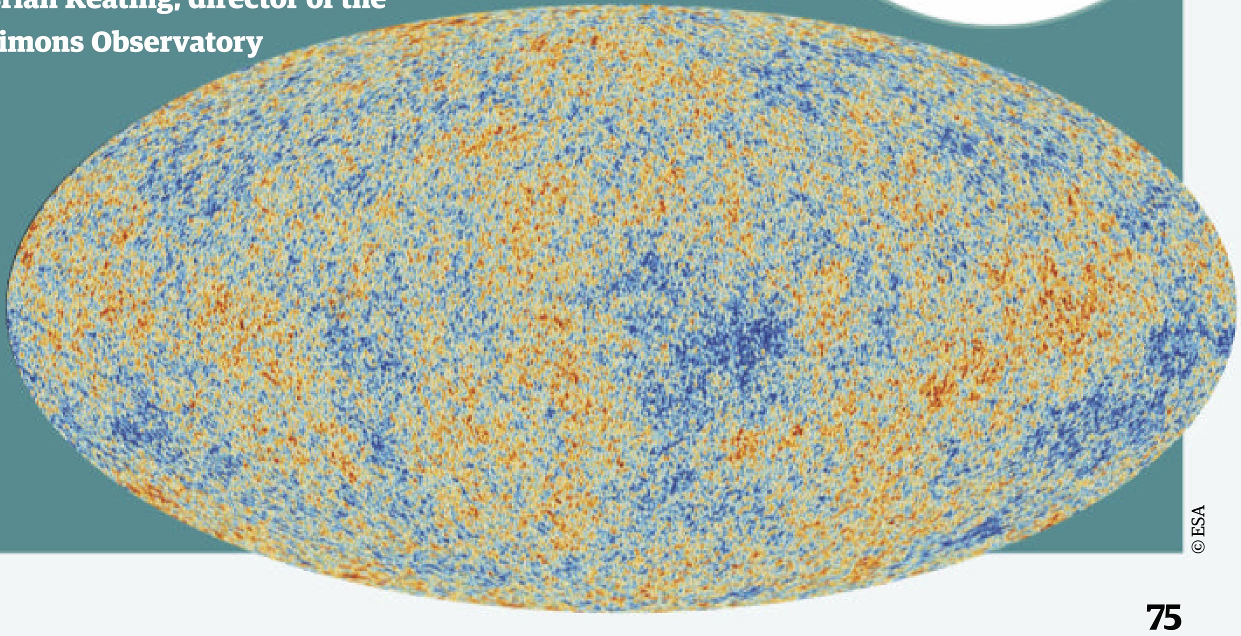
The CMB is made up of photons from the primeval oven that the universe forged the first elements in. These are the lightest elements, and when they were formed, the leftover binding energy of formation was released in the form of heat. That heat propagated throughout the universe for 13.8 billion years until it arrived at our telescopes.

If you've used a microwave, you know they are efficient absorbers of water, and water is present in Earth's atmosphere. The atmosphere above the South Pole is very desert-like. There are few water molecules in the atmosphere above the South Pole. We don't want these photons that are so precious to us, and so few, travelling across the universe, and all of a sudden they smash into a water molecule in our atmosphere. All of our microwave telescopes need to be built at high elevation, in very cold climates or both.

Brian Keating, director of the Simons Observatory

Did you know?

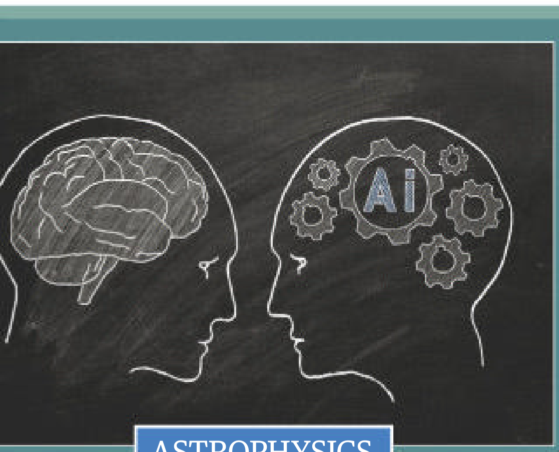
Astronomers Arno Penzias and Robert Wilson first detected the cosmic microwave background.



© ESA

ASK Space

Our experts answer your questions



© Alamy

Left: Human intelligence and artificial intelligence depicted on a blackboard

ASTROPHYSICS

What are the advantages of using citizen scientists over artificial intelligence?

There are still many places where humans are better than computers. One of the reasons is that our visual system is very good at taking information on different scales at once. Another is that people are distractible - people can be distracted by the unusual and the unexpected.

Lots of great discoveries have come from when people have found things that they weren't expecting, or that we didn't ask them to look for. The ability to be doing one task, and then going "hang on. There's something weird here," is very natural and very human. It's something volunteers are better at than experts. Experts have a hard-coded understanding of what they should be looking at.

For many of the problems that we are dealing with, as the datasets get larger and larger, we definitely need machine learning to do most of the work for us. There's no way we're going to cope with the information that's coming from future telescopes without machines doing the bulk of the work. But if you take humans and put them in the loop, not only do you get a better result by combining them, your machine can do better.

Chris Lintott, Oxford University

© NASA

Right: BLAPs are most likely the result of a merger of a binary star system

STARS

What are blue large-amplitude pulsators (BLAPs) and how do they differ from other pulsating stars?

Blue large-amplitude pulsators are almost half-an-hour pulsators, so their pulsation periods are between 20 and 40 minutes, and they have exceptionally large-amplitude changes. They differ from other variable stars because of the high-amplitude change in very short periods.

We know classical Cepheids, RR Lyrae and Mira stars are variable stars of much longer periods, consisting of days, weeks or even months. If you compare BLAPs to Cepheids, Cepheids extend over a larger fraction of the star's magnitude, but their periods are much shorter. If we compare this to our Sun, a typical BLAP is about 70 per cent the diameter of the Sun. However, the change in the surface is remarkably large, because about 13 per cent is the change in the BLAPs' diameter.

If you imagine that it takes only half an hour to make this change, it goes incredibly fast. What differentiates this pulsator from others is that other pulsators are mostly red giants, which are cool stars of about 3,000 to 5,000 Kelvin. These BLAPs are variable stars that are very hot. They have temperatures of about 30,000 Kelvin, making them appear blue.

Dr Pawel Pietrukowicz, University of Warsaw, Poland

PLANETS

Can a planet exist without a sun?

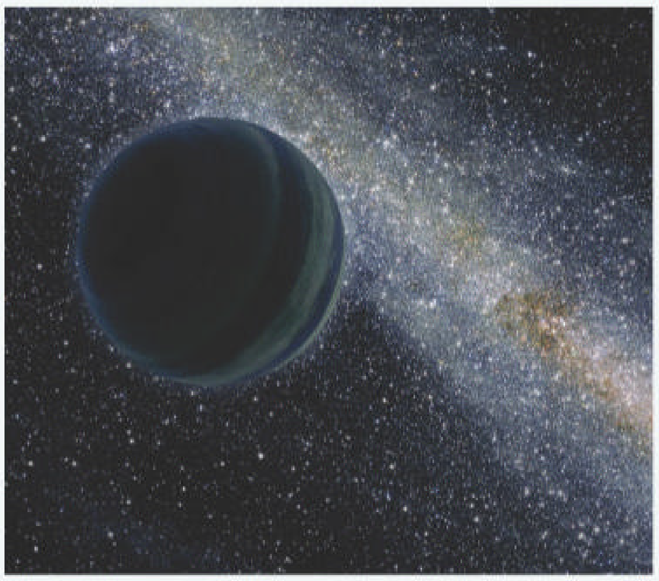
There are roughly 20 planets known that are free-floating and not orbiting any star, so the answer to this question is yes. Although maybe not entirely...

Most planets are thought to form in big discs around newly born stars called protoplanetary discs, and these planets get to live their lives orbiting their parent star. However, as the planetary system is building itself up, the orbits of planets can be highly dynamic, which could lead to planets colliding - which is how we think Earth got its Moon - or even being ejected out of the system entirely.

The interstellar object 'Oumuamua is thought to be such a planetary body that was flung out of its own stellar system and is currently travelling through our own Solar System. It's thought that there are many planets that share this fate, and some astronomers have estimated that there are more of these 'free-floating' planets than there are stars in the Milky Way.

While most planets need a sun to be made, they don't need one to exist, and can be found outside of stellar systems. There are also the planets that live around dead stars which give us insight into the Solar System's own future, and those thought to be made from the death of very large stars... but that's a topic for another time.

Dr Christopher Manser, Imperial College research fellow at Imperial College London



© NASA/JPL-Caltech

Right: Artist's impression of a rogue planet

SPACE EXPLORATION

How do you service a satellite?

Though the vast majority of satellites were not designed to be serviced, NASA is looking into ways to make it possible to extend their operational lives. Similar to how a car can be repaired and receive more fuel, satellite servicing seeks to make the same options available to satellites. Most satellites use fuel to maintain orbit control, so the depletion of fuel can end a satellite's life. In addition, parts wear out and components fail or become obsolete, which can also prematurely end or limit a satellite's usefulness. Servicing can entail orbit relocation, or can be more ambitious with the addition of robotic replacement of components or the transfer of fuel in space.

Satellite servicing efforts have been limited thus far due to cost. Astronauts famously repaired the Hubble Space Telescope with a series of Space Shuttle missions from 1993 to 2009. Satellite servicing is becoming more economically viable with the decrease in launch costs and the advancement of technology. The use of common interfaces or cooperative servicing aids in future satellite designs will make servicing more common.

In order to service a satellite, a servicer must meet up with the satellite while flying thousands of miles per hour. A servicer needs to manoeuvre and perform autonomous rendezvous and proximity operations using cameras, machine-vision systems and high-speed avionics. Once the servicer mates with the satellite, dexterous robots and specialised tools can be used to transfer fuel to the satellite. The first-ever refuelling of a satellite not designed to be serviced will be demonstrated by NASA's On-orbit Servicing, Assembly and Manufacturing 1 (OSAM-1) mission.

Brent Robertson, NASA project manager for the On-orbit Servicing, Assembly and Manufacturing 1 (OSAM-1) mission

Left: Artist's concept of OSAM-1

> "A SERVICER MUST MEET UP WITH THE SATELLITE WHILE FLYING THOUSANDS OF MILES PER HOUR"
>
> BRENT ROBERTSON

Did you know?

Of the 11,139 satellites that have been launched by humanity, around 7,389 remain in orbit.

© NASA

WHAT'S IN THE SKY?

IN THIS ISSUE...

78 What's in the sky? Stay up late or get up early for the best views the summer sky has to offer

82 Month's planets Jupiter takes pride of place in the dawn sky, while Mars and Venus grace the twilight

84 Moon tour See the lovely phenomenon of earthshine: the 'old Moon in the new Moon's arms'

85 Naked eye and binocular targets Distant galaxies and fascinating stars can be seen

86 Deep sky challenge Challenge yourself to find the faint stars, clusters and nebulae of summer

88 The Northern Hemisphere The central part of our galaxy is teeming with clusters

90 Astroshots of the month The best of our readers' astrophotography

92 Telescope review We put the Celestron Omni XLT AZ 102 to the test

96 In the shops Our pick of the best products for astronomy and space fans

> "DURING OPPOSITION, AN OBJECT IS VISIBLE FOR THE WHOLE NIGHT"

RED LIGHT FRIENDLY

In order to preserve your night vision, you should read our observing guide under red light

18 JUL
Pluto reaches opposition in Sagittarius, glowing at magnitude +14.9

19 JUL
Asteroid 6 Hebe is well placed for observation in Aquila, glowing at magnitude +8.4

Source: Wikipedia commons © Andrew Jones

24 JUL
The Moon and Saturn make a close approach, within 3°42' of each other in Capricornus

26 JUL
Conjunction between Saturn and the Moon in Aquarius

26 JUL
The Moon and Saturn make a close approach, passing within 3°55' of each other in Aquarius

28 JUL
The Piscis Austrinids reach their peak of five meteors per hour

2 AUG
Saturn reaches opposition in Capricornus, glowing at magnitude +0.2

Source: Wikipedia commons © Chris Isherwood

JARGON BUSTER

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

24 JUL

Conjunction between Saturn and the Moon in Capricornus

26 JUL

The Moon and Venus make a close approach, passing within 3°53' of each other in Virgo

Source: Wikipedia commons © Brocken Inaglory

30 JUL

The Southern delta-Aquariids reach their peak of around 25 meteors per hour

30 JUL

Asteroid 12 Victoria reaches opposition, glowing at magnitude +8.8 in Aquila

30 JUL

The alpha-Capricornids reach their peak of around five meteors per hour

11 AUG

Conjunction between the Moon and Venus in Virgo

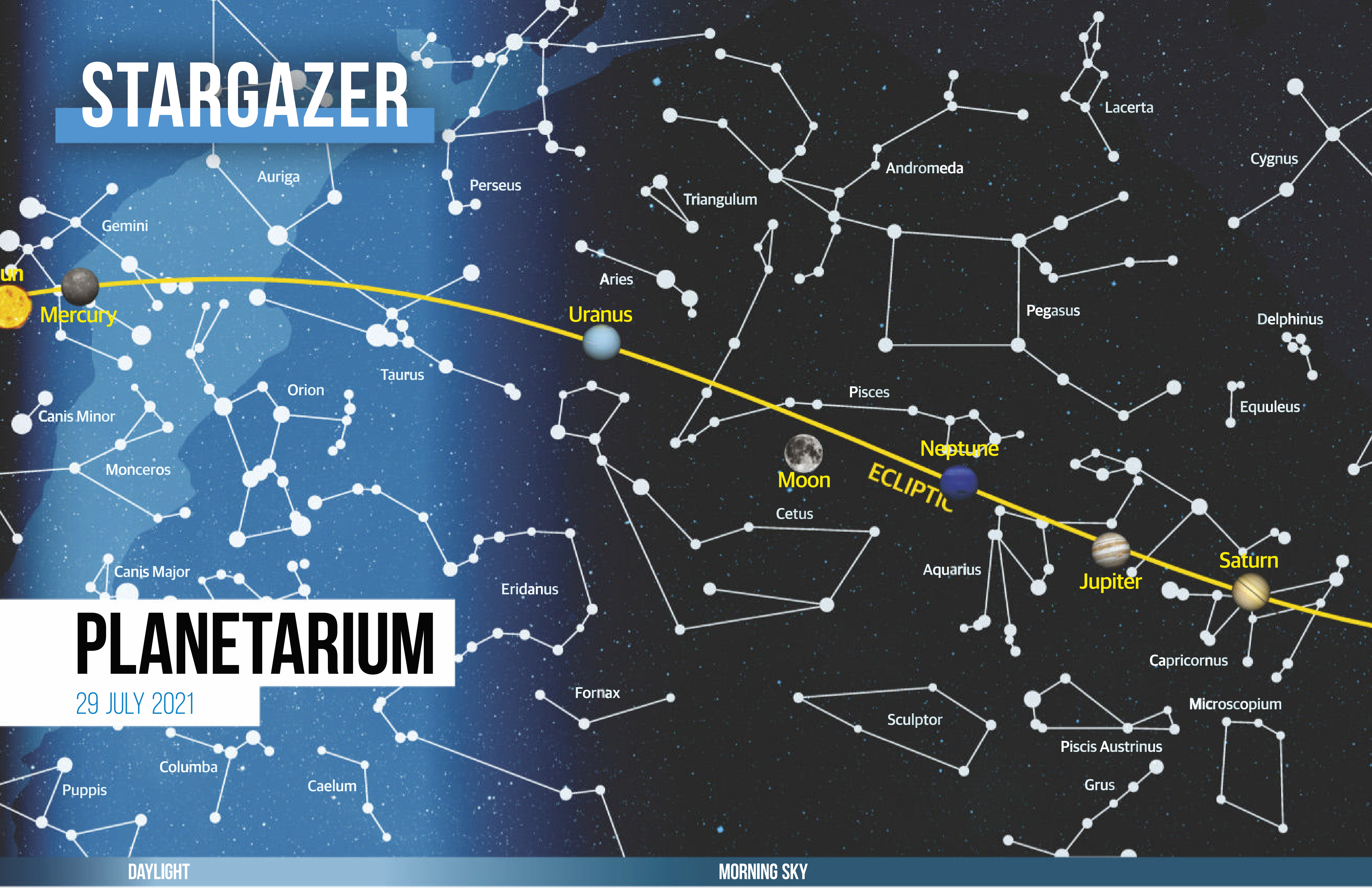
© Wikiolo

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

STARGAZER

PLANETARIUM

29 JULY 2021



MOON CALENDAR

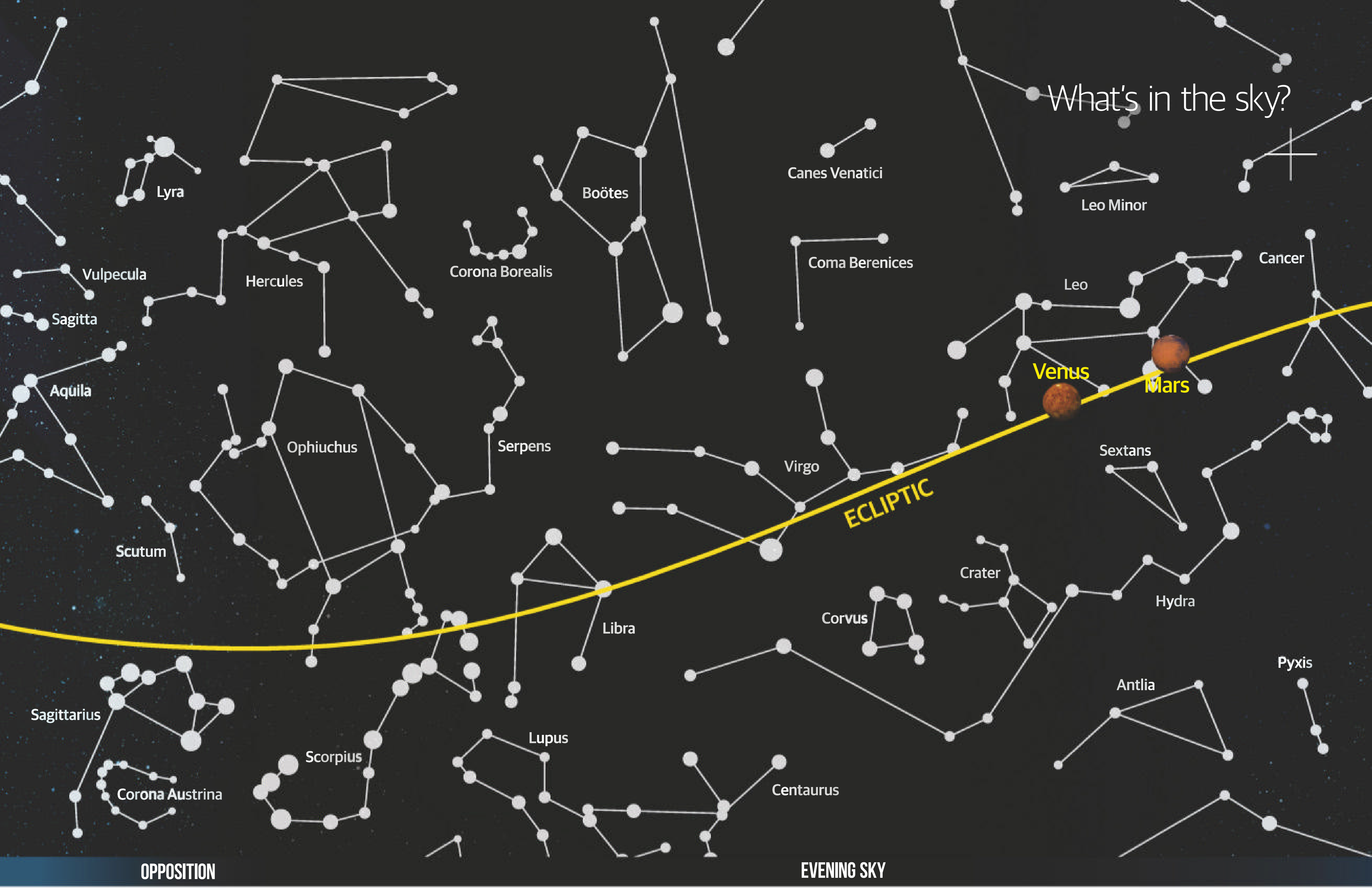
* The Moon does not pass the meridian on 22 July

			15 JUL 31.3% ◓10:57 ◒--:--	16 JUL 42.3% ◒00:00 ◓12:16	17 JUL FQ 53.9% ◒00:16 ◓13:37	18 JUL 65.6% ◒00:33 ◓15:01
19 JUL 76.5% ◒05:53 ◓16:27	20 JUL 86.1% ◒01:19 ◓17:53	21 JUL 93.4% ◒01:53 ◓19:14	22 JUL --.--%* ◒02:40 ◓20:23	23 JUL 98.1% ◒03:43 ◓21:15	24 JUL FM 99.9% ◒04:59 ◓21:53	25 JUL 98.7% ◒06:21 ◓22:20
26 JUL 94.9% ◒07:43 ◓22:41	27 JUL 88.9% ◒09:02 ◓22:58	28 JUL 81.3% ◒10.18 ◓23:13	29 JUL 72.5% ◒11:30 ◓23:26	30 JUL 63.0% ◒12:41 ◓23:41	31 JUL TQ 53.2% ◒13:50 ◓23:56	1 AUG 43.4% ◒15:00 ◓--:--
2 AUG 33.9% ◓00:15 ◒16:09	3 AUG 25.0% ◓00:38 ◒17:17	4 AUG 17.0% ◓01:08 ◒18:21	5 AUG 10.2% ◓01:47 ◒19:47	6 AUG 4.9% ◓02:37 ◒20:04	7 AUG 1.4% ◓03:40 ◒20:41	8 AUG NM 0.2% ◓04:51 ◒21:09
9 AUG 1.2% ◓06:08 ◒21:32	10 AUG 4.7% ◓07:26 ◒21:50	11 AUG 10.6% ◓08:46 ◒22:07	12 AUG FQ 18.6% ◓10:06 ◒22:23	13 AUG 28.5% ◓11:26 ◒22:39		

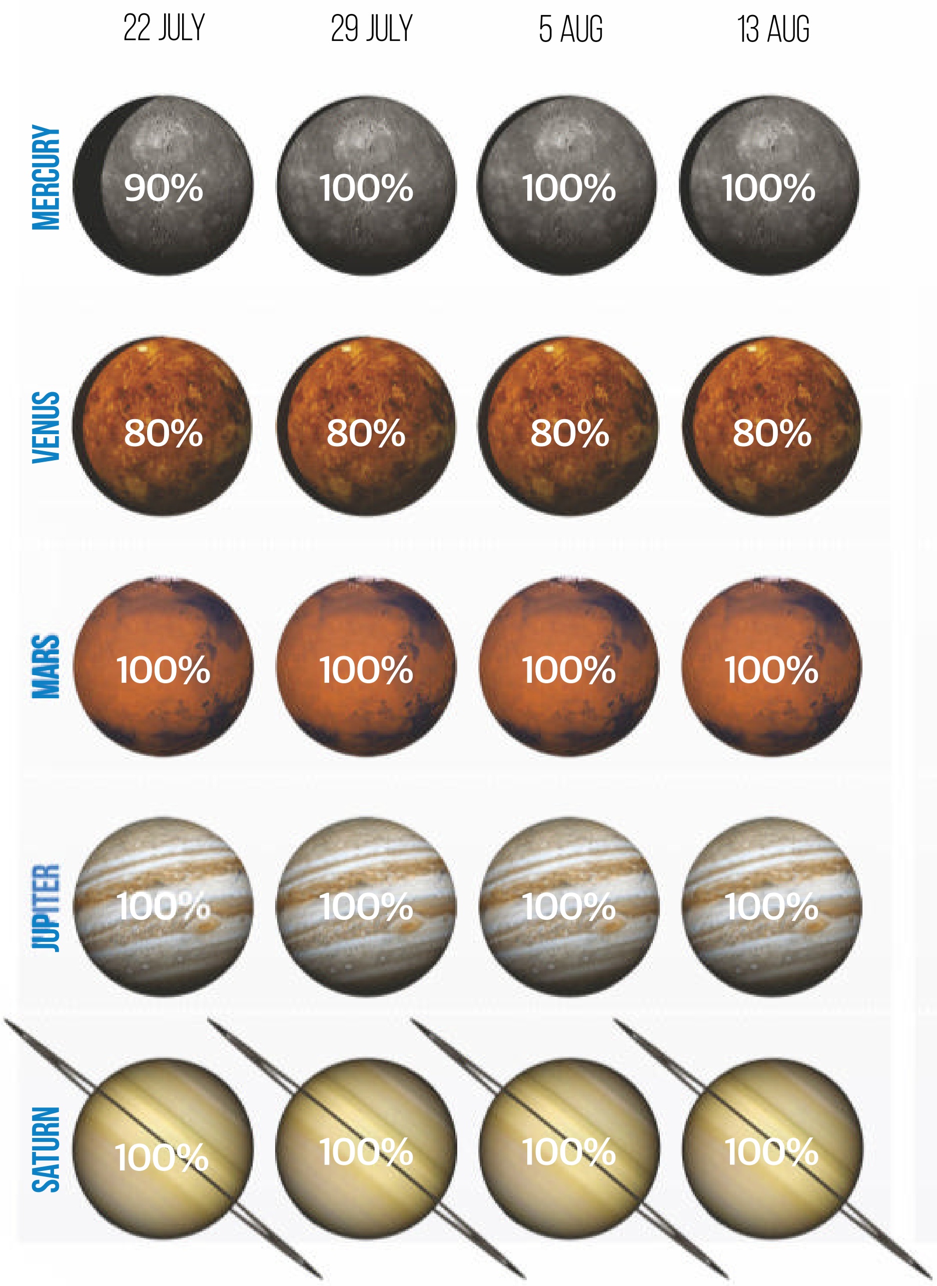
FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

% Illumination
◓ Moonrise time
◒ Moonset time

What's in the sky?



ILLUMINATION PERCENTAGE



	22 JULY	29 JULY	5 AUG	13 AUG
MERCURY	90%	100%	100%	100%
VENUS	80%	80%	80%	80%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

PLANET POSITIONS

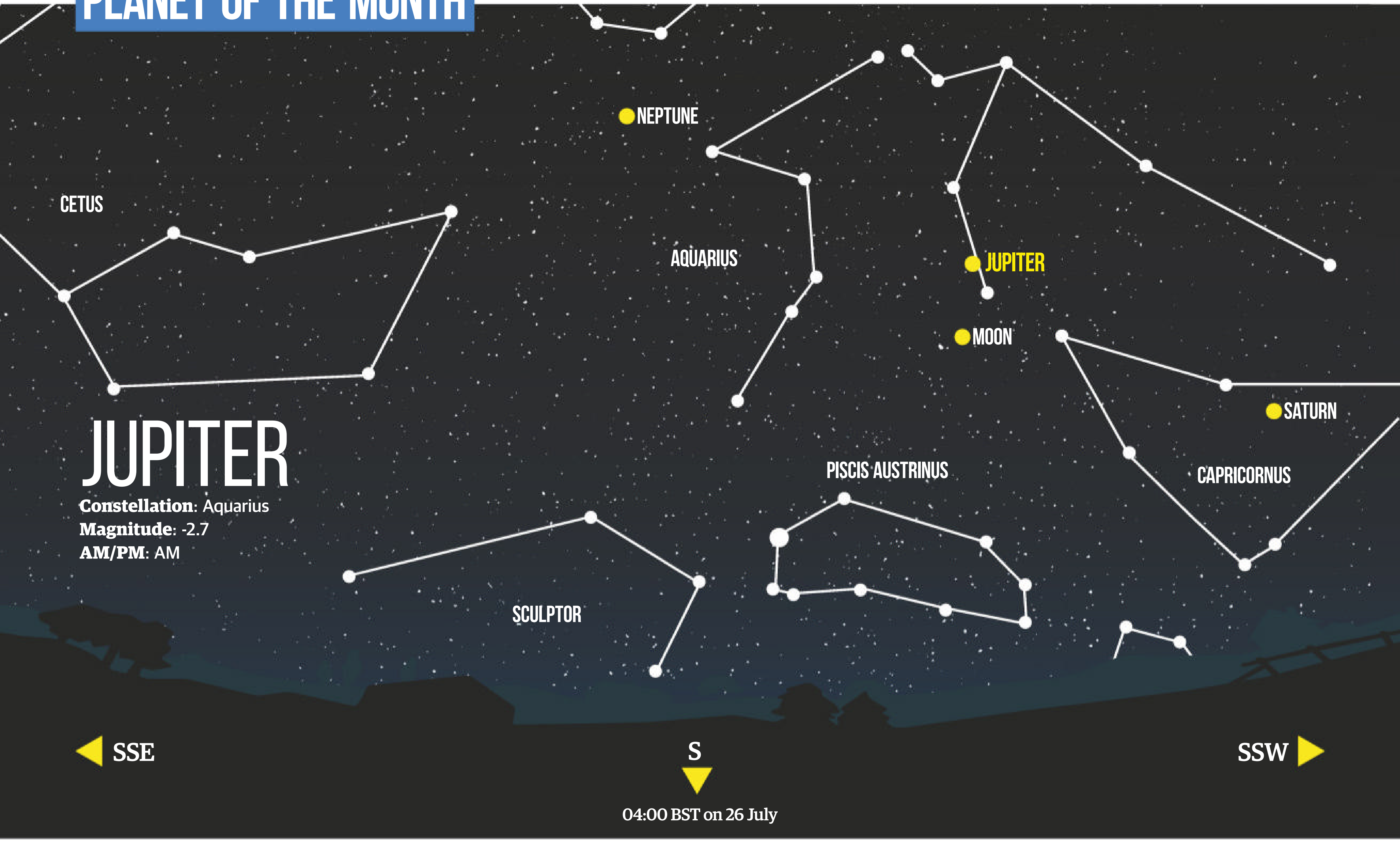
All rise and set times are given in BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
15 JULY	06h 19m 28s	+22° 26' 24"	Gemini	-0.7	03:38	20:08
22 JULY	07h 14m 58s	+22° 49' 09"	Gemini	-1.2	04:06	20:42
29 JULY	08h 17m 11s	+21° 11' 29"	Cancer	-1.9	04:50	21:02
5 AUG	09h 17m 04s	+17° 39' 02"	Leo	-1.7	05:46	21:11
13 AUG	10h 17m 00s	+12° 14' 36"	Leo	-0.8	06:46	21:06
15 JULY	09h 36m 43s	+15° 58' 19"	Leo	-3.9	07:40	22:44
22 JULY	09h 54m 57s	+16° 12' 05"	Leo	-3.9	06:02	21:11
29 JULY	10h 41m 00s	+09° 50' 48"	Leo	-3.9	08:24	22:17
5 AUG	11h 11m 52s	+06° 27' 05"	Leo	-4.0	08:44	22:00
13 AUG	11h 46m 25s	+02° 24' 37"	Virgo	-4.0	09:11	21:44
15 JULY	09h 32m 48s	+15° 47' 55"	Leo	+ 1.8	07:37	22:39
22 JULY	09h 49m 51s	+14° 20' 11"	Leo	+ 1.8	07:36	22:20
29 JULY	10h 06m 44s	+12° 47' 59"	Leo	+ 1.8	07:35	22:01
5 AUG	10h 23m 29s	+11° 11' 43"	Leo	+ 1.8	07:30	21:37
13 AUG	10h 42m 29s	+09° 17' 22"	Leo	+ 1.8	07:30	21:17
15 JULY	22h 13m 32s	-12° 08' 13"	Aquarius	-2.8	22:51	08:49
22 JULY	22h 11m 19s	-12° 22' 24"	Aquarius	-2.8	22:24	08:19
29 JULY	22h 08m 38s	-12° 38' 50"	Aquarius	-2.8	21:52	07:44
5 AUG	22h 05m 35s	-12° 57' 01"	Aquarius	-2.8	21:24	07:12
13 AUG	22h 01m 45s	-13° 19' 06"	Aquarius	-2.9	20:50	06:34
15 JULY	20h 55m 31s	-18° 07' 53"	Capricornus	+0.3	22:10	06:57
22 JULY	20h 53m 32s	-18° 16' 42"	Capricornus	+0.2	21:39	06:24
29 JULY	20h 51m 28	-18° 25' 42"	Capricornus	+0.2	21:12	05:55
5 AUG	20h 49m 22s	-18° 34' 41"	Capricornus	+0.2	20:41	05:22
13 AUG	20h 46m 59s	-18° 44' 40"	Capricornus	+0.2	20:09	04:48

THIS MONTH'S PLANETS

Jupiter takes pride of place in the dawn sky for early risers, while Mars and Venus grace the twilight

PLANET OF THE MONTH



JUPITER

Constellation: Aquarius
Magnitude: -2.7
AM/PM: AM

04:00 BST on 26 July

Our Planet of the Month this issue is the largest planet in the Solar System: mighty Jupiter. Between mid-July and mid-August Jupiter will be visible all through the night. Rising in the ESE at around 22:00, looking like a blue-white 'star', it will then trace out a low arc across the southern sky during the night, eventually fading from view as the light of the approaching dawn washes it from the western sky.

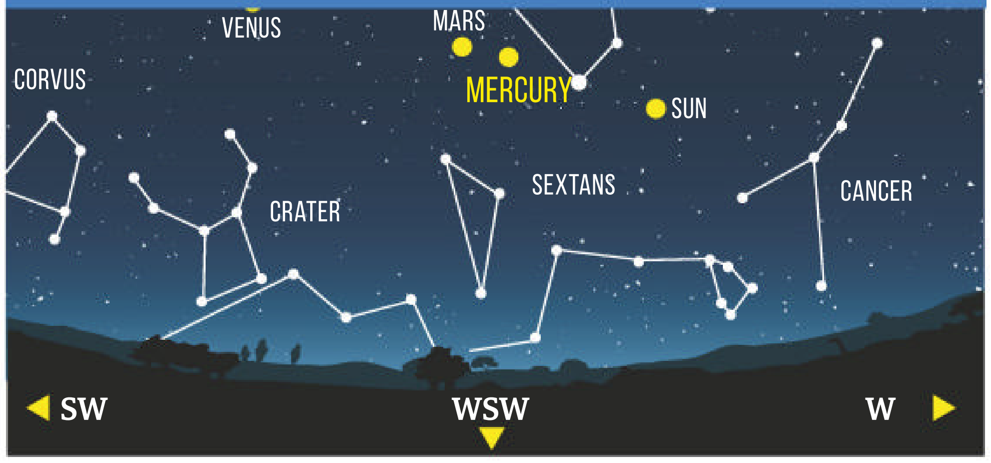
Though Jupiter will be shining at magnitude -2.7, at this time of year, thanks to summer's late sunsets and early sunrises, the sky never gets truly dark, so although Jupiter will be an easy naked-eye object, it won't appear as strikingly bright as that magnitude suggests. It will look noticeably brighter than Saturn, which will be shining to its left all through the summer.

Jupiter is one of the most photographed planets in the Solar System, and it's easy to understand why. A gas giant world so enormous that our own planet could fit across its disc a dozen times, and so huge that it could contain a thousand Earths, Jupiter has a thick, turbulent atmosphere that churns relentlessly, constantly changing its appearance.

When we look at Jupiter through a small telescope, we can see several horizontal bands of dark clouds crossing its flattened, pale disc. Larger telescopes show more detail, but visiting space probes have given us our clearest views of this amazing world. Today the Juno orbiter is sending back breathtaking images of Jupiter, showing how fierce winds sculpt its multicoloured clouds into ragged streamers and roiling oval-shaped storms.

Jupiter has so many moons – 79 at the last count – that in many ways it's like a mini solar system orbiting the Sun. The four largest of these moons, discovered by Galileo in 1610, can be seen through just a pair of binoculars as tiny points of light shining close to Jupiter itself, almost lost in the planet's glare. But you won't see all four of these 'Galilean satellites' every night: the number visible changes from night to night as they whirl around Jupiter, sometimes passing in front of or behind the giant planet.

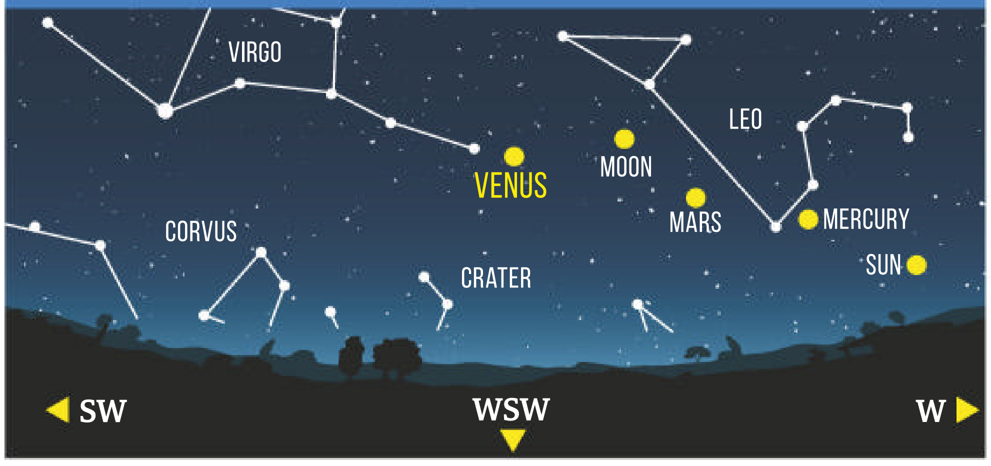
MERCURY 18:00 BST on 15 August



Constellation: Gemini **Magnitude:** +0.4 **AM/PM:** PM

Mercury, the closest planet to the Sun, starts our observing period as a reasonably bright morning star, visible low in the sky before sunrise quite close to Gemini's most famous star cluster, Messier 35. As the days pass Mercury's visibility will quickly decrease as it appears to move closer and closer to the Sun, and by the end of July it won't be observable.

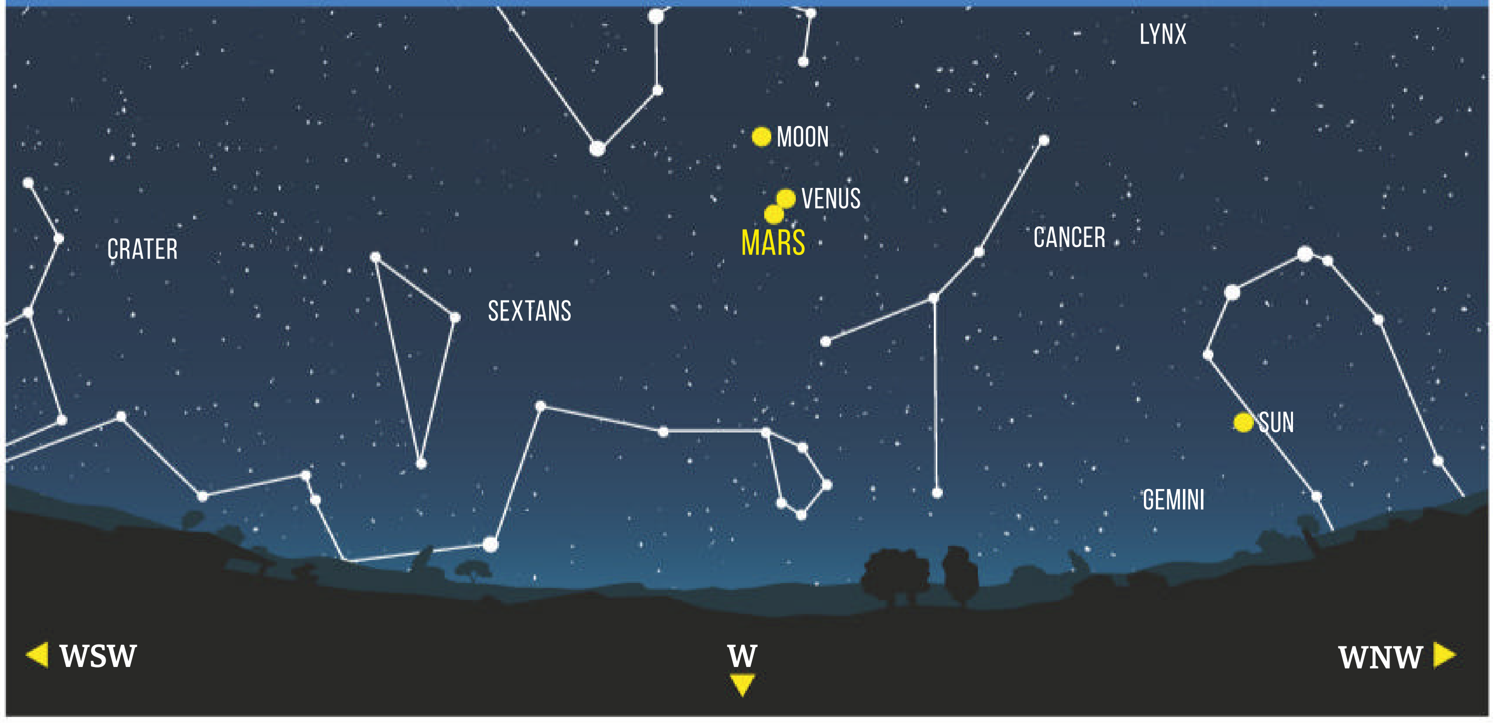
VENUS 20:00 BST on 10 August



Constellation: Leo **Magnitude:** -3.9 **AM/PM:** PM

Venus will be an evening star during our observing period, appearing as a spark of light low in the west after sunset. Look closely at it as twilight deepens on 15 July and you'll see a fainter 'star' very close to it on its lower right. This is Mars, and the two worlds will be less than one-and-a-half degrees – or three Moon widths – apart, looking beautiful together.

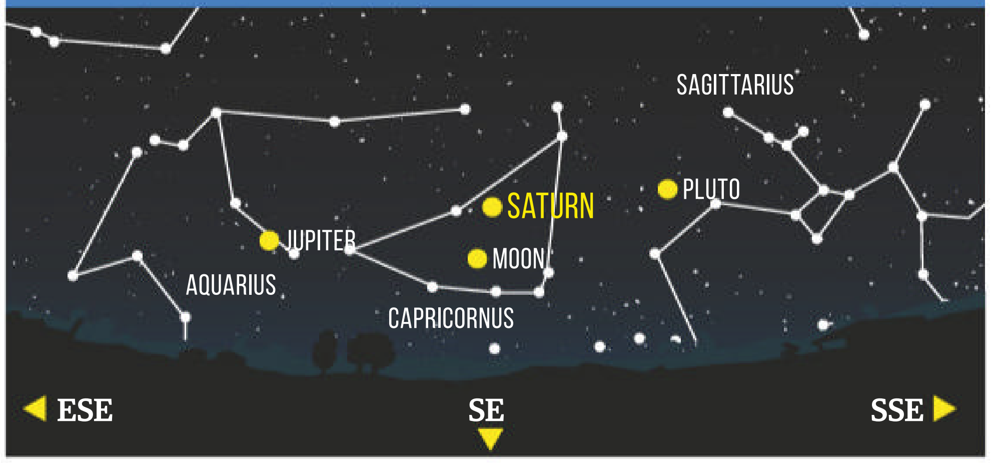
MARS 20:00 BST on 12 July



Constellation: Leo
Magnitude: +1.8
AM/PM: PM

Mars is an evening object at the start of our observing period, but shining at only magnitude +1.8 – approximately as bright as Polaris, the Pole Star – it will be quite hard to see in the bright twilight sky, and will be a little harder to see each night as it drifts towards the Sun. However, in mid-July the Red Planet will be in the same binocular field of view as much brighter and more obvious Venus, which will make it easy to find: on the evening of 15 July they will be just under one-and-a-half degrees apart, and will look great through binoculars or small telescopes.

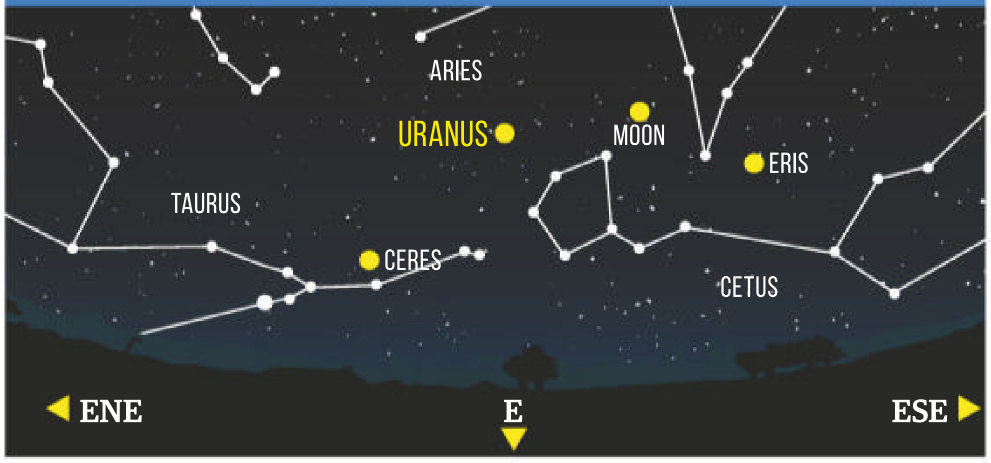
SATURN 23:00 BST on 24 July



Constellation: Capricornus **Magnitude:** +0.3 **AM/PM:** PM

After gracing our morning skies for many months, Saturn is now rising well before midnight, making it an evening object. At the start of our observing period it rises just as the sky starts to darken, followed by brighter Jupiter. After rising it traces out a low arc across the sky, never gaining much height above the horizon before fading from view low in the west at sunrise.

URANUS 02:00 BST on 31 July



Constellation: Aries **Magnitude:** +5.9 **AM/PM:** AM

Uranus is a morning object through June and into July, a little higher in the sky and farther away from the Sun each morning. At magnitude +5.9 Uranus would be a naked-eye object for many under a dark sky, but with the sky in June and July never growing truly dark, it's likely Uranus' faint light will be overwhelmed, and you'll need a pair of binoculars to find it.

TOP TIP!

If you have an SLR camera you can photograph earthshine using a zoom lens. Put your camera on a tripod to keep it steady.

MOON TOUR

EARTHSHINE

See the beautiful 'old Moon in the new Moon's arms'

Take a quick look at any map of the Moon and you will see that it is covered with many fascinating features, some even visible to the naked eye. On any night when our planet's natural satellite is visible in your sky, you will be able to look at it through a telescope, or even just a pair of binoculars, and peer down into the dark depths of its dramatic craters, see sunlight bathing the jagged peaks of its magnificent mountain ranges and, of course, roam its dark seas of ancient, frozen lava.

Sometimes though, the Moon itself is the star of the show. The sight of a bloated full Moon rising from behind the trees on a warm summer evening is quite magical, and the silvery 'Cheshire Cat' smile-like crescent of a young Moon hanging above the western horizon in the hours after sunset, as the sky darkens, is so striking that it often makes everyone stop what they're doing and just stare up at it.

But for a few days at the start of each lunar month the Moon offers us something truly beautiful. When the Moon is what most people call new - an extremely thin crescent hanging low in the dusk sky - it is often possible to see the rest of the Moon's disc illuminated with a very subtle glow. In comparison to the silvery-white crescent, the darker portion of the disc seems to be painted a shade of grey-blue, or even lavender, just bright enough to allow us to see surface features as vague, dark shapes through our binoculars or telescopes. This phenomenon used to be called ashen light or, more romantically, 'the old Moon in the new Moon's arms' but modern astronomers and sky-watchers know it as earthshine.

Earthshine is one of those rare astronomical terms which actually describes quite accurately something we can see. What we're observing during the first few days of the lunar month is the part of the Moon not yet lit up directly by sunlight being illuminated by a much subtler light reflecting off Earth - with sunbeams bouncing up off its oceans, cloudy atmosphere and icy poles. Since this light is much weaker than direct sunlight, it isn't powerful enough to do much more than cast a feeble glow on the lunar landscape, but that's enough to allow us to see the rest of the Moon framed by the beautiful crescent of a so-called new Moon.

When is the best time to see earthshine? The very best times to see it in the Northern Hemisphere are in spring and autumn, when the young Moon is high in a dark sky after sunset or before sunrise. But throughout the year earthshine is at its most obvious to the naked eye during the first four or five days of the lunar month, when the contrast between it and the much brighter crescent is at its greatest. After day five it's possible to see earthshine through a telescope for another couple of days, but the best time to enjoy it is on days two and three - that's when the Moon has climbed high enough in the sky and moved far enough away from the sunset glow for it to be most noticeable.

To enjoy seeing earthshine, all you need are your eyes. You'll easily be able to see the dark part of the Moon glowing with a gentle, soft light. The Earth-lit Moon is particularly beautiful when there's a bright planet shining in the sky close to it, and we'll always make sure to give you advance warning of when that will be happening in our monthly sky notes here in **All About Space**.

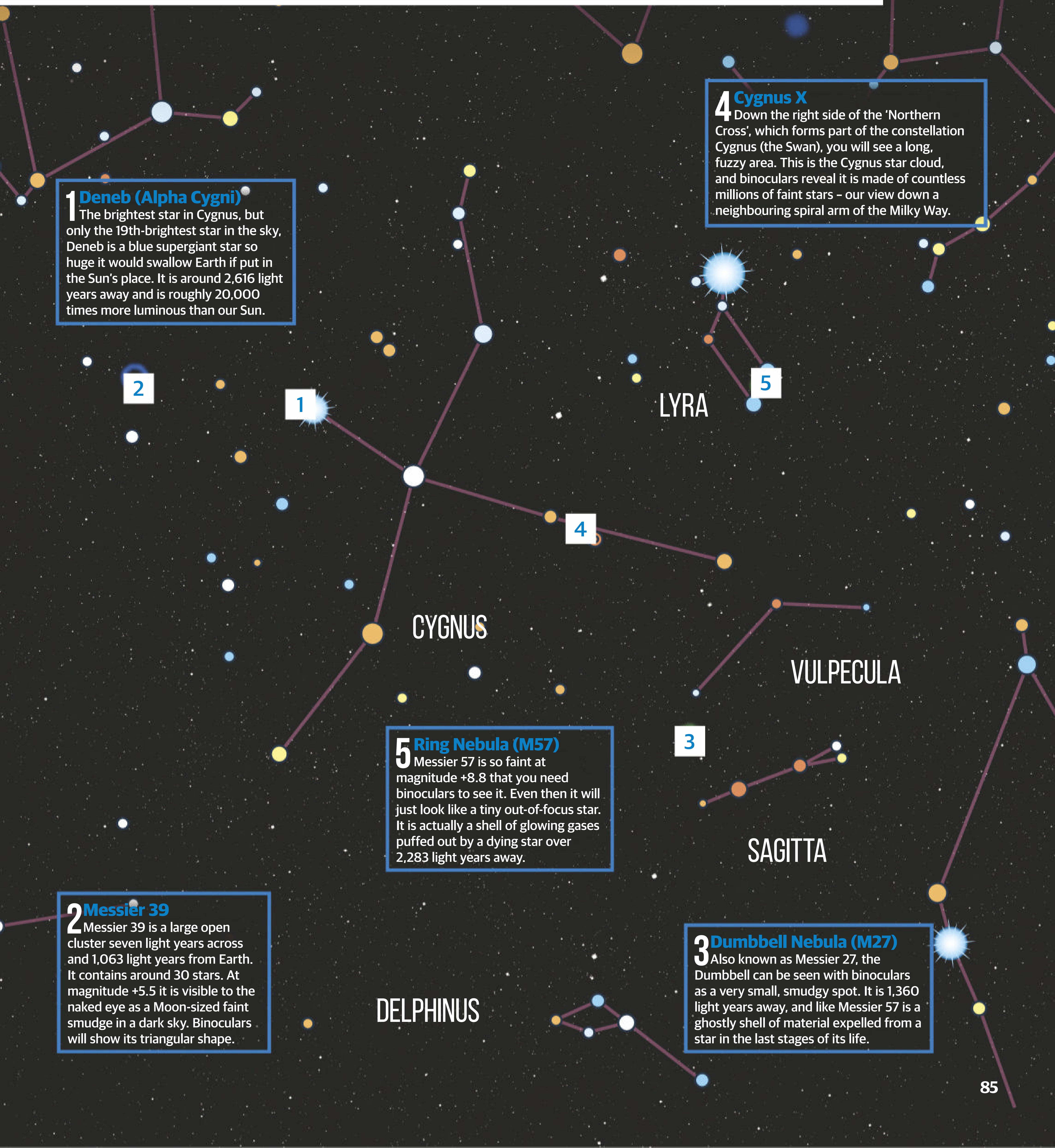
Through a telescope or pair of binoculars the view is simply beautiful: the subtle colours of the Earth-lit part of the Moon are enhanced, and the contrast between the bright crescent and the rest of the Moon is much more obvious. You'll also be able to see the lunar seas as dark stains across the surface, and bright craters such as Copernicus and Aristarchus as grey-white spots.

The summer months are not quite as ideal for viewing earthshine, but if your sky is clear on the evening of 10 July, you should still be able to see it as the young Moon hangs above the horizon after sunset, although you might need binoculars to see it properly or improve the view.

© ESO

NAKED EYE & BINOCULAR TARGETS

Distant galaxies and fascinating stars can be seen late on summer nights



1 Deneb (Alpha Cygni)
The brightest star in Cygnus, but only the 19th-brightest star in the sky, Deneb is a blue supergiant star so huge it would swallow Earth if put in the Sun's place. It is around 2,616 light years away and is roughly 20,000 times more luminous than our Sun.

2 Messier 39
Messier 39 is a large open cluster seven light years across and 1,063 light years from Earth. It contains around 30 stars. At magnitude +5.5 it is visible to the naked eye as a Moon-sized faint smudge in a dark sky. Binoculars will show its triangular shape.

3 Dumbbell Nebula (M27)
Also known as Messier 27, the Dumbbell can be seen with binoculars as a very small, smudgy spot. It is 1,360 light years away, and like Messier 57 is a ghostly shell of material expelled from a star in the last stages of its life.

4 Cygnus X
Down the right side of the 'Northern Cross', which forms part of the constellation Cygnus (the Swan), you will see a long, fuzzy area. This is the Cygnus star cloud, and binoculars reveal it is made of countless millions of faint stars – our view down a neighbouring spiral arm of the Milky Way.

5 Ring Nebula (M57)
Messier 57 is so faint at magnitude +8.8 that you need binoculars to see it. Even then it will just look like a tiny out-of-focus star. It is actually a shell of glowing gases puffed out by a dying star over 2,283 light years away.

DEEP SKY CHALLENGE

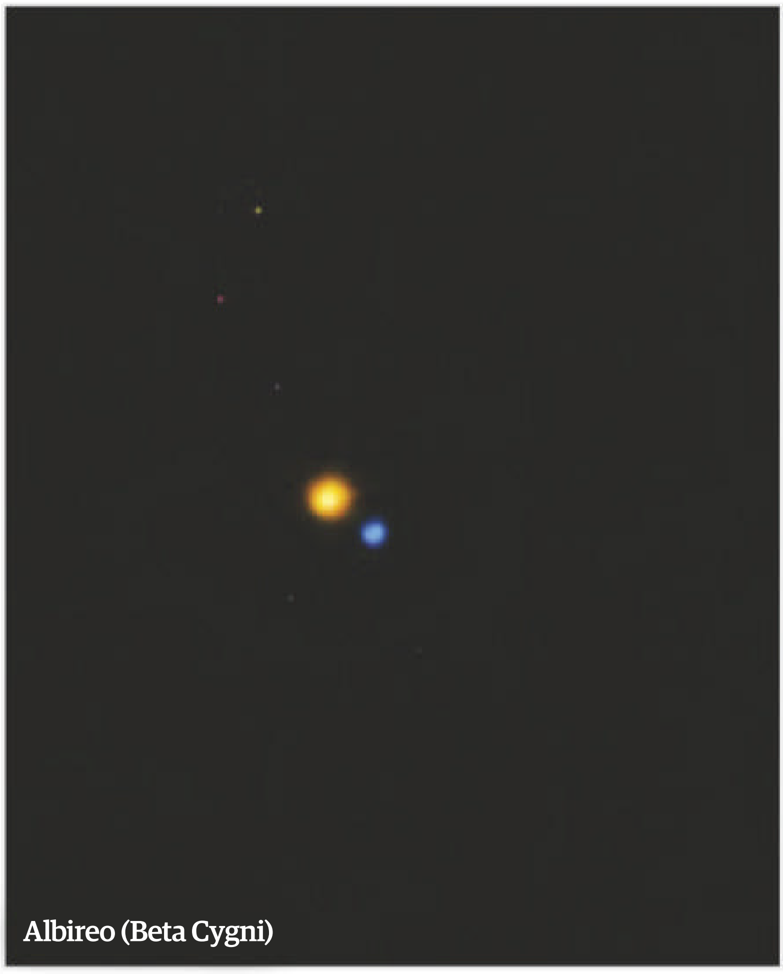
STARS, CLUSTERS AND NEBULAE OF SUMMER

Glittering stellar groupings, a star's corpse and a beautiful double star can be seen through any size of telescope

Many think the summer sky is too bright to allow observation of 'faint' and 'fuzzy' deep-sky objects, but if you stay up late the sky is just dark enough to let you see some lovely sights. Around one and two in the morning - providing the sky isn't lit up with a display of bright blue and silver noctilucent clouds - a telescope will give you very pleasing views of some of astronomy's most famous objects.

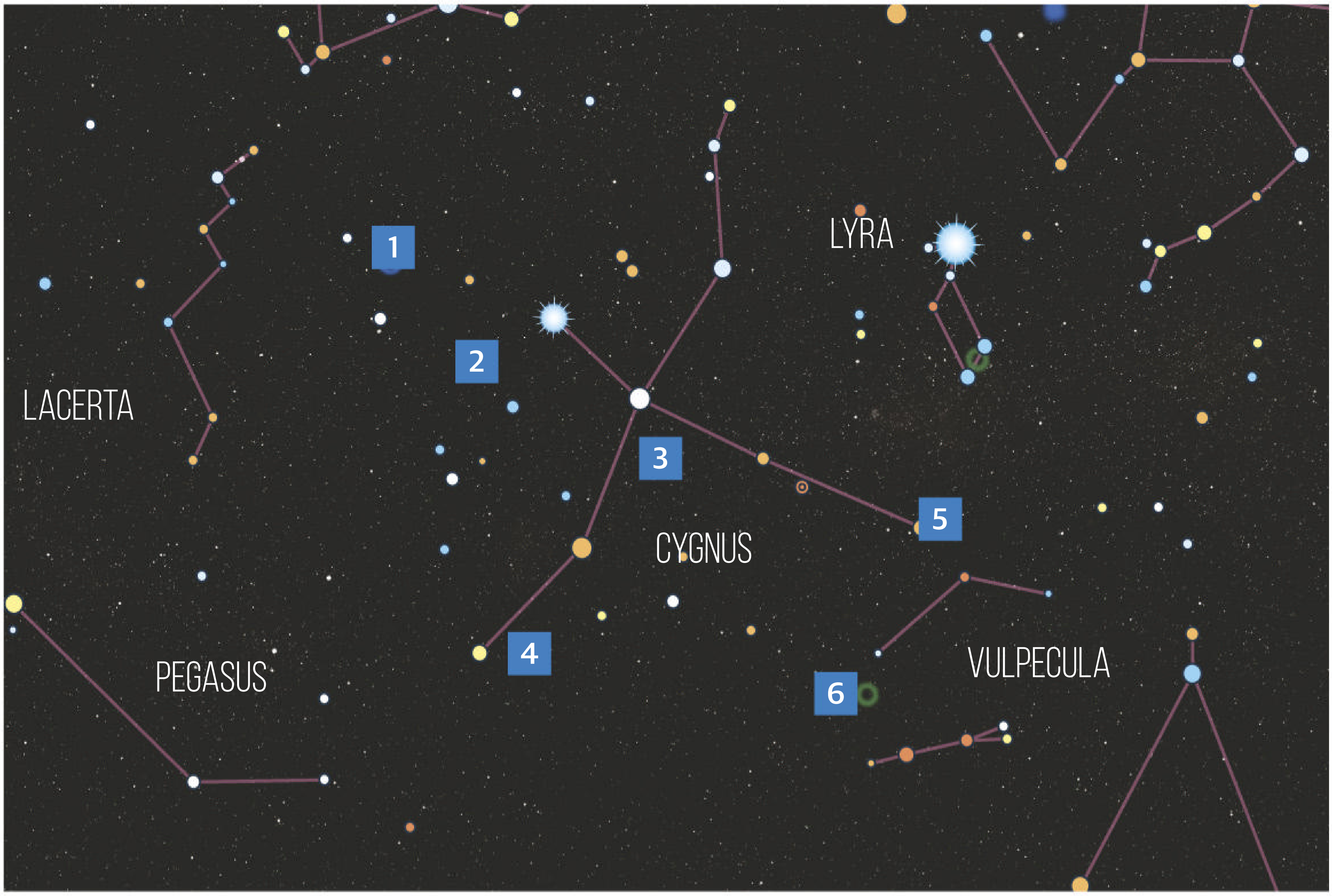
Although the broad, frothy band of the Milky Way dominates the sky, running right through the centre of Cygnus (the Swan), or the Northern Cross, cutting it and the whole sky in half, embedded in it are subtly coloured nebulae - regions where stars are being born. Elsewhere you can see the ghostly remains of dying or dead stars and much more. Even a small telescope will give you a beautiful view of one of the loveliest and most popular double stars in the whole sky.

Don't be put off by the pessimists who claim that the summer sky is a write off. As long as you don't mind losing sleep, there's still lots to see.



Albireo (Beta Cygni)

Source: Wikipedia Commons © Hewholooks



© ESA/Hubble & NASA

Messier 39

Source: Wikipedia Commons © Jim Mazur

"EVEN A SMALL TELESCOPE WILL GIVE YOU A BEAUTIFUL VIEW"

1 Messier 39

Messier 39 is a loose open star cluster, roughly triangular in shape and the same angular diameter as the Moon. It is best seen in small telescopes using low magnifications.

3 Messier 29

This magnitude +6.6 open cluster contains only a few scattered stars, forming the shape of an open box. Small to medium telescopes pick it out well from the background sky.

5 Albireo (Beta Cygni)

One of the most beautiful double stars in the sky, any telescope splits Albireo into a third-magnitude gold star and a magnitude +4.7 sapphire-hued star, 20 arcseconds apart.

2 North America Nebula (NGC 7000)

Although this famous emission nebula covers as much sky as around four full Moons, a telescope is needed to pick out its distinctive shape.

4 Veil Nebula (Sharpless 103)

The seventh-magnitude Veil Nebula consists of two arcs of faint gas. It's the remains of a star that blew up between 5,000 and 8,000 years ago.

6 Dumbbell Nebula (Messier 27)

This famous nebula is just a smudge in small telescopes. Medium and large-aperture telescopes show its twin lobes of blue-green gas.

THE NORTHERN HEMISPHERE

Well into summer, nebulae are visible and the central part of our galaxy is teeming with clusters

Now fully in the midst of summer, the shorter, warmer nights offer a splendid selection of nebulae, star clusters and bright stars to observe. Red supergiant Arcturus proudly makes its appearance known in the constellation of Boötes (the Herdsman). The unmistakable Summer Triangle is easily observed this month, with the stars Altair, Deneb and Vega in the constellations of Aquila, Cygnus and Lyra respectively marking each of its corners.

Summer is an ideal time to see the Milky Way, with Sagittarius and Scorpius marking its centre – here you'll be able to see a selection of clusters, including the Ptolemy Cluster, also known as Messier 7.

USING THE SKY CHART

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

MAGNITUDES

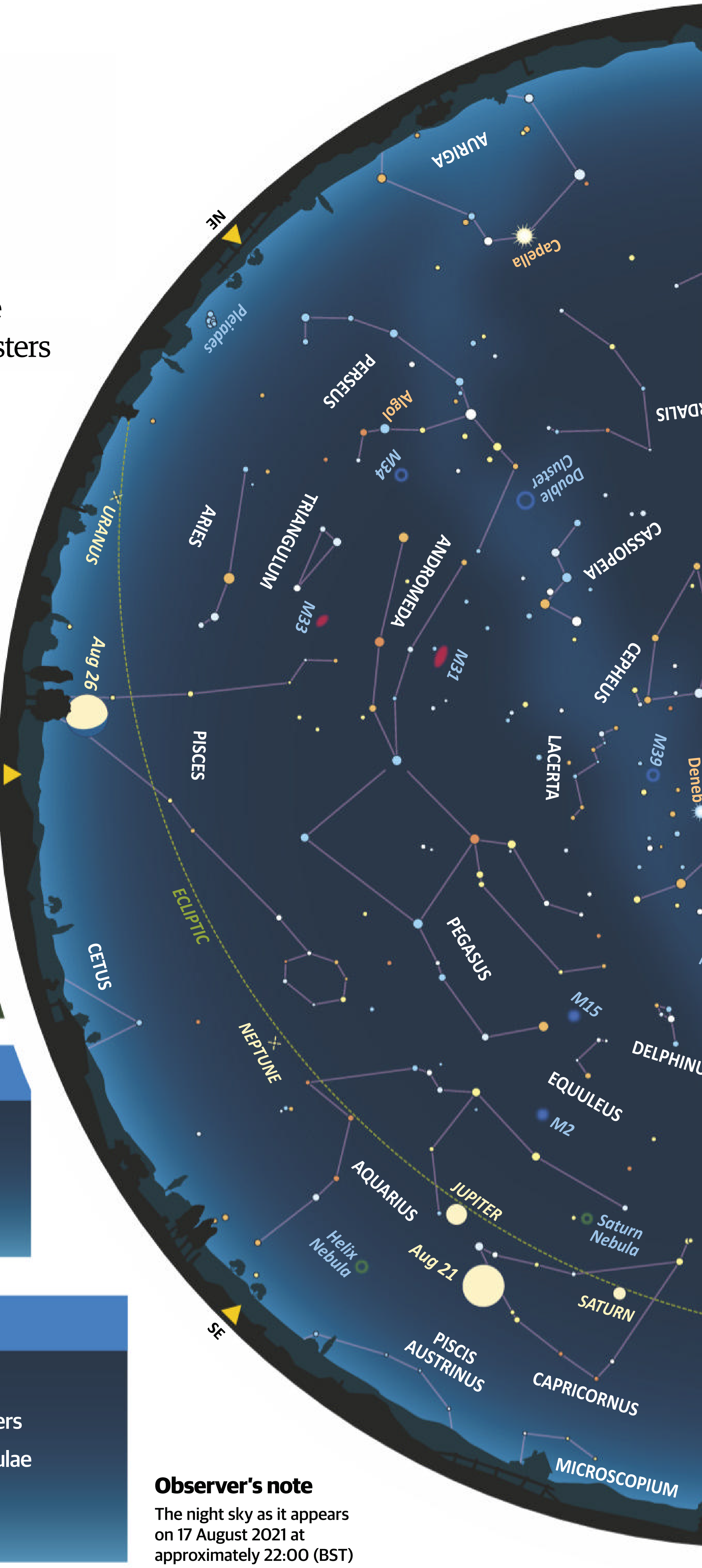
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

SPECTRAL TYPES

- O-B
- A
- F
- G
- K
- M

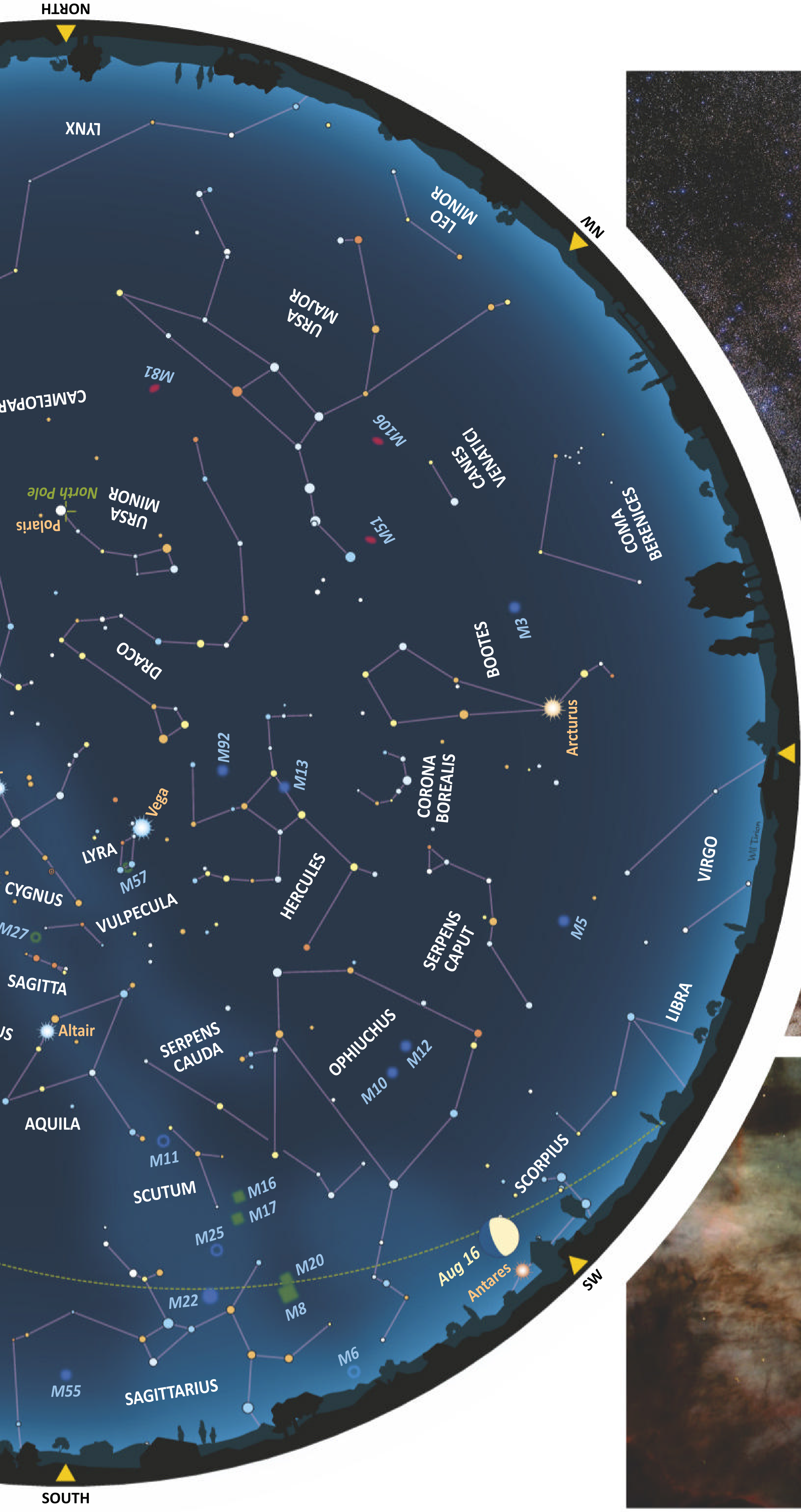
DEEP-SKY OBJECTS

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



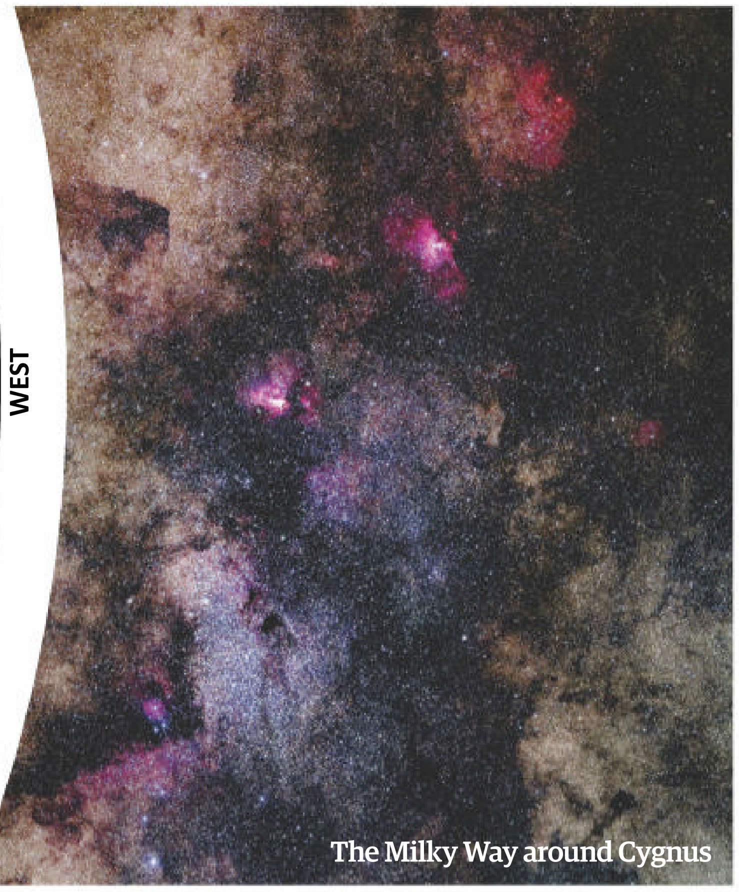
Observer's note

The night sky as it appears on 17 August 2021 at approximately 22:00 (BST)

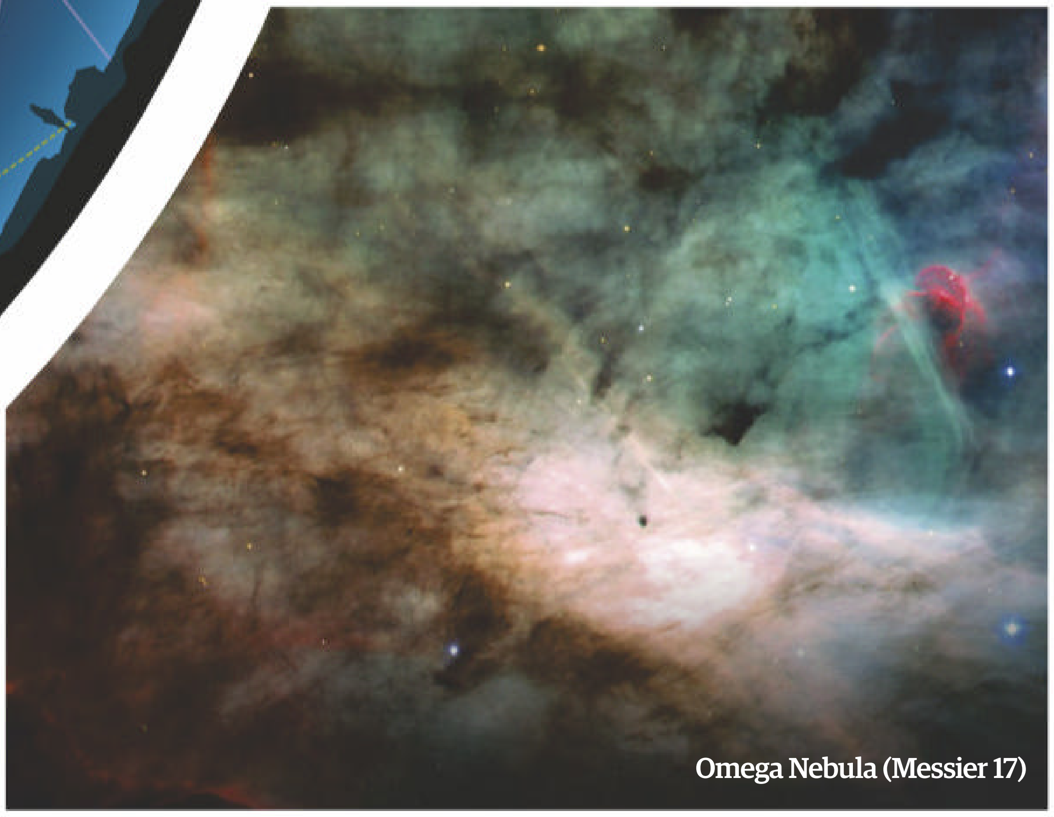


Eagle Nebula (Messier 16)

© Getty


The Milky Way around Cygnus

© Getty


Omega Nebula (Messier 17)

© Getty

18+

WHAT IS
AVAXHOME?

AVAXHOME -

the biggest Internet portal, providing you various content: brand new books, trending movies, fresh magazines, hot games, recent software, latest music releases.

Unlimited satisfaction one low price
Cheap constant access to piping hot media
Protect your downloadings from Big brother
Safer, than torrent-trackers

18 years of seamless operation and our users' satisfaction

All languages
Brand new content
One site

AVXLIVE.ICU

AvaxHome - Your End Place

We have everything for all of your needs. Just open https://avxlive.icu

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**

Samuel Bleyen

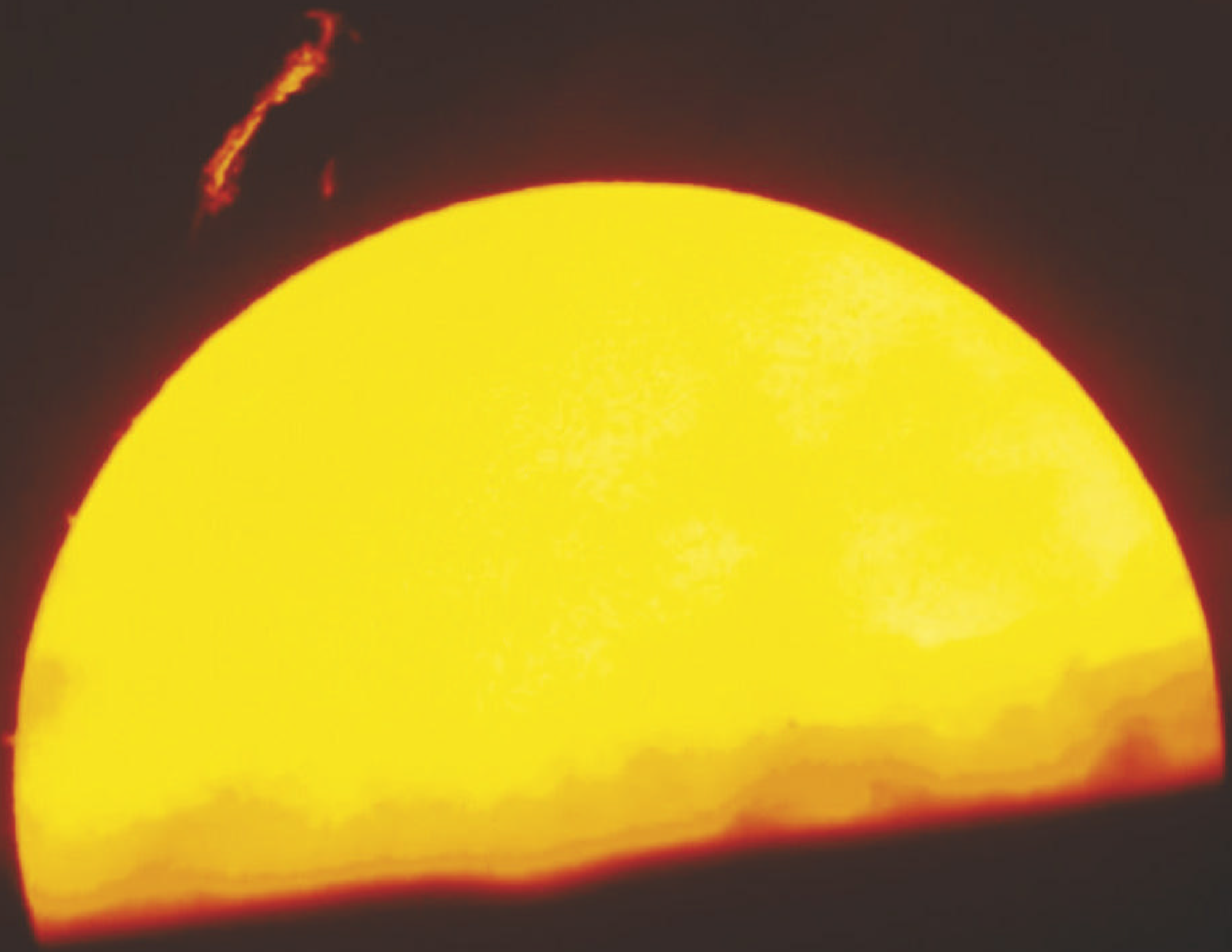
Location: Dublin, Ireland

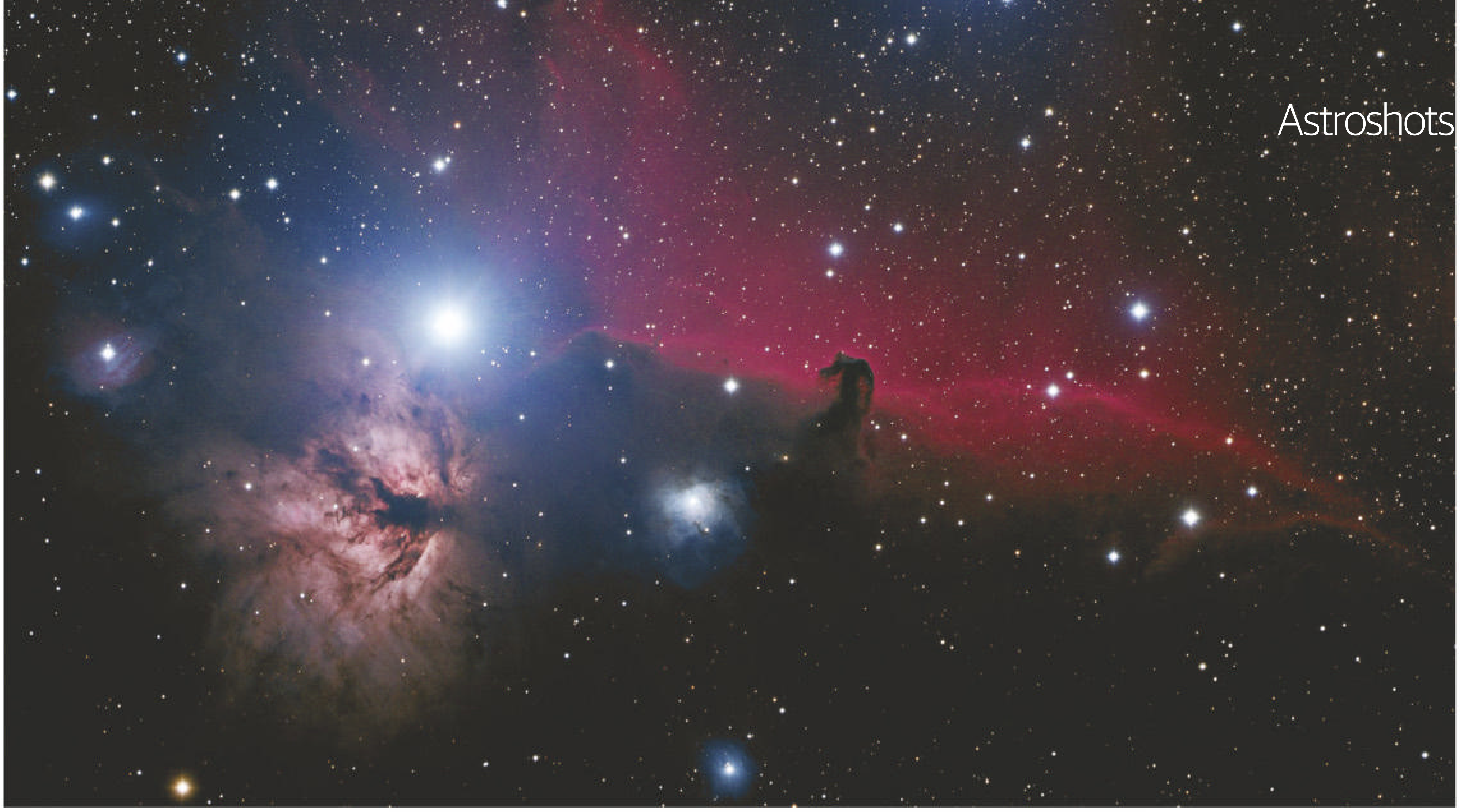
Telescope: Solarscope SV-60 Solarview H-alpha

"My interest in astronomy began when I was a teenager. Although I do a great deal of astronomy during the night – observing galaxies, nebulae, star clusters, planets and the constellations – my real passion lies with solar astronomy. Using my solar telescope and a Canon EOS 600D DLSR camera, I imaged a large prominence lifting off the solar limb back in July. The Sun was about to set behind the rooftops and some clouds were gathering on the western horizon as well. The prominence lifted off quite suddenly, and it was over in a few minutes – luckily I was in the right place at the right time."

> "THE PROMINENCE LIFTED OFF QUITE SUDDENLY, AND IT WAS OVER IN A FEW MINUTES"

Below: A solar prominence lifting off the limb of the Sun





Warren Keller

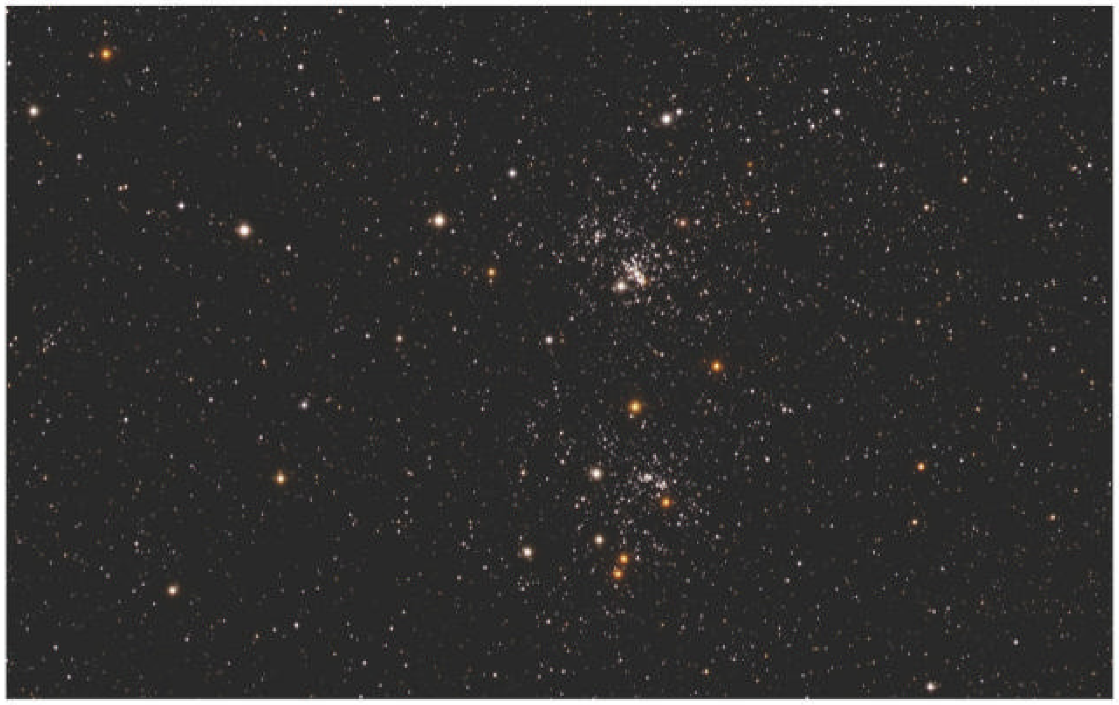
Location: West Virginia, US

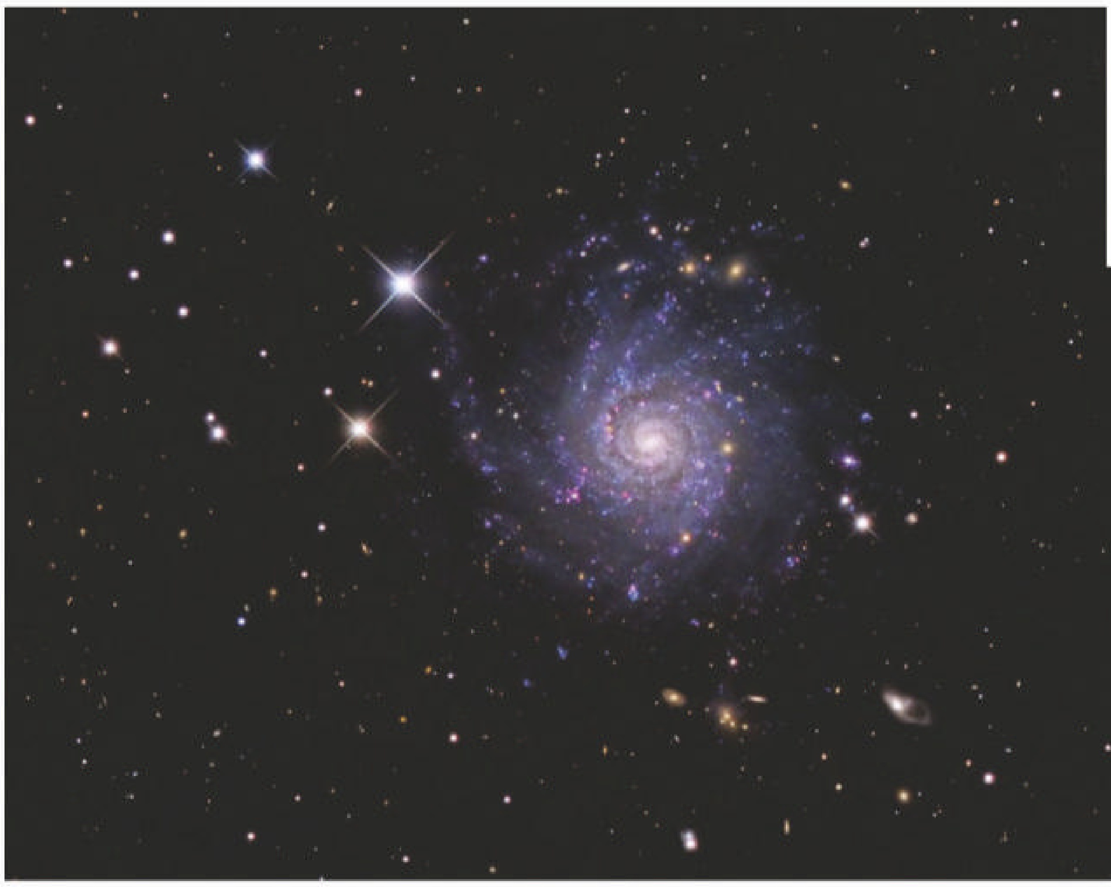
Telescope: 16" RCOS Ritchey-Chrétien owned by the University of North Carolina

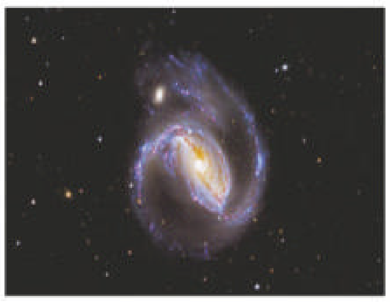
"I'm an advanced astrophotographer and teacher and have been published as an author and photographer in many astronomy magazines, as well as many places on the internet, including NASA's Astronomy Picture of the Day (APOD). I have also been a consultant for Celestron, where I co-designed AstroFX software for the Nightscape camera. And I'm now a part-time representative for QSI Imaging."

Above: The Horsehead Nebula (Barnard 33)

Right: Double Cluster (NGC 869 and NGC 884)







Above: Spiral galaxy NGC 1097

Left: Spiral galaxy IC 5332

Jaspal Chadha

Location: London, UK

Telescope: Takahashi TOA-130

"I have been imaging for around two-and-a-half years now after spending years looking through various telescopes and eyepieces, where I enjoyed learning all about the objects in the night sky. After months of research and trial and error, I finally invested in a set-up that I thought would work for me. My biggest challenge has been to fend off the myths around imaging in light-polluted areas, as I live in London. I started out with DSLR astrophotography, but now use a CCD to capture a wide range of night-sky targets."

REVIEW

CELESTRON OMNI XLT AZ 102

Boasting a first-class finish, this refractor offers the serious sky-watcher clear, magnified views of the Solar System

Reviewed by Gemma Lavender

TELESCOPE ADVICE

Cost: £325 (approx. $451)

From: Amazon

Type: Refractor

Aperture: 4.01"

Focal length: 25.98"

BEST FOR...

- BEGINNERS
- MEDIUM BUDGETS
- PLANETARY VIEWING
- LUNAR VIEWING
- BRIGHT DEEP-SKY OBJECTS

With the Celestron Omni XLT Omni 102, the sky-watcher gets a refractor that exudes quality. Aimed at intermediate-level astronomers with a reasonable knowledge of telescopes due to its complex German equatorial mount, this beautifully finished instrument promises to last for many years with a minimum level of maintenance.

The Omni 102 features high-quality optics – painted with Celestron's StarBright XLT coating to maximise light transmission – on the finest grade of glass. The optical system also makes use of aspheric shaping technology to minimise spherical aberration, a visual defect where incoming light is focused at different points. The result is that resolution and clarity are affected, causing blurry views of the night sky.

The refractor comes with a 25mm eyepiece, 1.25-inch star diagonal, heavy-duty stainless-steel tripod, accessory tray, spirit level, Starry Night Special Edition software and a 6x30 finderscope. That's a good amount of accessories to get started with, but the telescope will need further eyepieces to reach the optical system's highest and lowest useful magnifications of 240x and 15x.

On unboxing, we noted that the Omni 102 is of exceptional quality and design. Finished in a gunmetal-blue pearl with white accents, the telescope's high-quality finish is the centrepiece of this instrument. Slow-motion controls are included for fine-tuned night-sky navigation.

Since you don't need tools or fiddly screws and bolts to set up the telescope, it takes a mere five to ten minutes to put the Omni 102 together. The overall build is stable, with no sign of shaking or toppling over, and peering into the objective lens, the glass is beautifully coated. No residue of oil or glue was evident anywhere on the components.

One minor annoyance is the rack-and-pinion focuser. While it's fashioned from high-quality metal and performs well, these focusers have a tendency to slip when holding heavy eyepieces and supporting cameras. We recommend replacing it with a Crayford focuser for optimum performance and fine-tuning your views.

The Omni 102 weighs 6.26 kilograms, making it less than portable for those looking to travel beyond their backyard – if you're a sky-watcher who likes to chase the darkest skies, then we recommend either searching for a more portable option or having a vehicle to hand for transportation.

Unfortunately, the Omni 102 doesn't come with a wide range of observing accessories apart from the star diagonal, finderscope and 25mm eyepiece. But being versatile and having a useful maximum magnification of over 240x, the refractor will serve as a good instrument for years to come – an amateur astronomer won't outgrow it for some time. The multi-coated 25mm eyepiece has very good eye relief, and we were delighted to see that it's of excellent quality and build – just like the telescope it slots into.

Main: Assembly is a breeze, but the telescope is heavy and not easily portable

Left: The sleek, pearlescent design is very attractive

> "THE TELESCOPE'S HIGH-QUALITY FINISH IS THE CENTREPIECE OF THIS INSTRUMENT"

Right: One 25mm eyepiece is supplied, and is of high quality

The Omni 102 is a fine example of a small to medium refractor, and this became evident when we turned it to a selection of objects in a clear night sky. With its aperture and focal ratio, this telescope is more suited to views of the Solar System and Moon, but it also offers good views of a selection of deep-sky targets. We took advantage of a full Moon. Slotting the supplied 25mm eyepiece – which provides a magnification of 40x – into the 1.25-inch star diagonal, we were soon studying the lunar surface. The lenses are of superb quality; the StarBright XLT coating ensured bright and crystal-clear views as we toured craters and mare. Lunar rilles and mountains were also breathtaking. The Omni 102 drinks in plenty of light, so we recommend investing in a Moon filter for very good, superior contrast.

Bright crater Aristarchus was a stunning sight, as were the craters Kepler, Copernicus and Tycho, whose rays – made when material was thrown up during their progenitor impacts – could easily be detected by the refractor.

As we slewed across the Moon's surface, we noted the ease with which the German equatorial mount allowed the telescope tube to move. The mount's well-made stainless-steel tubular tripod legs are exquisite, providing excellent support to the telescope and a good, solid base when combined with the counterbalance: the extra weighting is especially useful for those wishing to try their hand at basic astrophotography.

Sadly, we did notice a degree of false colour – or chromatic aberration – which gave bright objects a blue-purple colouration. For the cost of the telescope, we did expect to see this through the optical system of the Omni 102, but we were relieved to see that it wasn't as severe as we had feared. In fact, the chromatic aberration is so minor that we quickly forgot about this minor problem in the telescope's optical system.

Putting the 6x30 finderscope to the test, we noted the clear and sharp views when we used it to guide us to the very bright -1.46-magnitude star Sirius in Canis Major (the Great Dog). We noted that views were sharp across a good proportion, with only slight trailing off in clarity around the field of view's edge.

We quickly moved over to gas giant Jupiter and its four largest moons: Ganymede, Io, Callisto and Europa. Overall views were impressive, and we were able to detect the gas giant's bands with ease, while its satellites appeared as specks of light either side of its brilliant disc.

FOR

- Breathtaking Solar System sights
- A superior, high-quality mount
- Sturdy and robust design
- Easy to accessorise for better views

AGAINST

- Few accessories supplied
- Some optical defects

We did note a halo around Jupiter brought about by the Omni XLT 102's optical system, which unfortunately didn't disappear until we fitted a blue filter. However, the planet's atmosphere stood out beautifully, playing up the cloud belts and the famous Great Red Spot.

With Venus making a dramatic presence in the sky, we took the opportunity to observe it. As with views of many bright objects, there was purple colour fringing around the planet's bland disc, but we were able to make out a phase with 60 per cent illumination as well as some atmospheric shading when we made use of a deep-blue filter.

The red giant star Betelgeuse in Orion (the Hunter) kept its stunning orange-red colour at 40x magnification. Meanwhile, the diffuse gas of the Orion Nebula (Messier 42) and its Trapezium Cluster were picked up easily with the additional help of averted vision. Both objects were picked out with impressive contrast and clarity, certainly a highlight of our tour of the night sky.

In terms of optical prowess, we can highly recommend the Omni XLT 102 – especially given the minimal colour fringing when observing bright targets like Jupiter and Venus. Due to its aperture size and focal ratio, this refractor is best suited to Solar System targets as well as fair views of bright nebulae and galaxies.

You don't get a great deal in the way of eyepieces in the package, but you do get a high-quality build for a moderate price – one that will last for many observing sessions to come, while being versatile enough to be accessorised with a full suite of add-ons.

Due to the advanced mount, we wouldn't recommend the Omni XLT 102 to sky-watchers without prior experience of using a telescope – especially if the astronomer isn't familiar with setting circles and using right ascension and declination coordinates.

However, for those who feel they can make the most of what the Omni XLT 102 has to offer, it is a great piece of kit for the serious sky-watcher and for those looking to try their hand at astrophotography.

Right: The whole build is of excellent quality and design, providing pleasing views

3 FREE DIGITAL BOOKS

FOR EVERY READER!

NEW
MISSIONS | FACTS | CHANCES OF LIFE
MARS
EXPLORE THE WONDERS OF THE RED PLANET
Digital Edition
NEW
From the makers of All About Space
Astronomy for Beginners
All you need to know to get started in astronomy
Set up your telescope
Explore the night sky
Master star charts
Digital Edition
CELEBRATING 50 YEARS SINCE THE MOON LANDING
MOON
EVERYTHING YOU NEED TO KNOW ABOUT OUR LUNAR NEIGHBOUR
Digital Edition
APOLLO PROGRAM | THE FAR SIDE | CRATERS & MORE

BOOK OF MARS

The history of Mars is intrinsically bound up with that of Earth - some scientists even think that the original building blocks of life came from there. The European Space Agency's Mars Express probe, undeterred by the failure of its Beagle 2 lander back in 2003, recently beamed back some of the clearest images yet of a crater filled with water ice in the northern lowlands of what was once thought to be an arid world. Despite a chequered history of failed spacecraft and the so-called 'Mars Curse', the Red Planet is finally giving up some of its secrets. In this book it's revealed what scientists know so far about the planet and the theories that may help us to understand it further, exploring how one day we could make it into another human home.

ASTRONOMY FOR BEGINNERS

Armed with nothing more than your eyes and a basic grasp of where to look in the night sky, you can embark on one of the most rewarding hobbies in the world. Planets, stars, constellations, nebulae, meteor showers and many other celestial objects can be spotted using only the naked eye. And for those with telescopes, the universe is a vast gallery of a trillion cosmic wonders. Easy-to-follow guides will furnish you with all the essentials, taking you on a journey from stargazing hobbyist to becoming a fully equipped astronomy enthusiast. With practical guidance, seasonal sky charts and pointers on how to spot some of the sky's most accessible sights, this new edition of **Astronomy for Beginners** will be your companion as you unravel the beauty of the sky.

BOOK OF THE MOON

We've been looking up at the Moon for millennia, but it was always just out of reach. Then everything changed. On 20 July 1969, humankind achieved what had previously been thought impossible: two astronauts landed on the surface of the Moon for the very first time. More Moon landings followed in an era since dubbed the golden age of space exploration, but our curiosity is far from sated. In the **Book of the Moon**, find out what really happened when Neil Armstrong and Buzz Aldrin stepped outside their Lunar Module and uncover what is being done to preserve that moment in history before taking a tour of lunar craters and maria. Learn how to take the perfect photograph of our lunar neighbour, and discover what's really on the Moon's far side.

DOWNLOAD YOURS NOW AT: SURVEYMONKEY.CO.UK/R/3FGFLNZ

IN THE SHOPS

The latest books, apps, software, tech and accessories for space and astronomy fans alike

FOR YOUR HOME BAR

GALAXY DUST RUM LIQUEUR

Cost: £19.99 / $29

From: firebox.com

1 According to scientists, Sagittarius B2 - a giant cloud of gas and dust 390 light years from the centre of the Milky Way - 'smells' like rum and 'tastes' like raspberries. Why not treat yourself to a drink that captures the essence of our galaxy. Enjoy it neat or make your own cosmic cocktails - all in the name of science. Made from an exquisite blend of white rum and sweet tart raspberries, this liqueur shimmers like stardust when you give it a swirl. This vegan-friendly rum liqueur is a guaranteed crowd pleaser. The 50cl bottle is 20% ABV.

FOR SUMMER

SPACE AGE ROCKET ICE LOLLY MOULDS

Cost: £5.95 (approx. $8.25)

From: rexlondon.com

2 Take your summer refreshments to a whole new level with these quirky ice lolly moulds. You don't have to be a rocket scientist to come up with some jaw-droppingly delicious lolly ideas that would make for the perfect treat on a hot summer's day. Simply fill the moulds with your choice of juice, smoothies or even yoghurt, then pop in the freezer and wait. Each mould measures ten centimetres (3.9 inches) in length and three centimetres (1.1 inches) at its widest point, and the handle is 3.5 centimetres (1.4 inches) long.

FOR ACCESSORISING

SCIENCE MUSEUM NASA BASEBALL CAP

Cost: £10 (approx. $13.90)

From: Science Museum

3 Created exclusively for the Science Museum, this NASA cap is the perfect summer accessory to keep the Sun out of your eyes. Feel like part of the NASA crew with this stylish navy-blue, brushed-cotton cap, which is printed in the UK. The baseball cap is designed with everyone in mind. It is available in one size but has an adjustable strap at the back to adjust for the size of your head. This cap would make for a great gift for the space enthusiast in your life.

4

5

> "MAKE YOUR OWN SOLAR FILTER AND SAFELY GAZE AT OUR IMPRESSIVE SUN"

6

FOR REACHING FITNESS GOALS

PLANETS OF THE SOLAR SYSTEM VIRTUAL RACES

Cost: £19.66 / $26.99 per challenge

From: adventure.mypacer.com

4 Set yourself a fitness goal of cosmic proportions with these limited-edition Solar System Pacer Virtual Adventure Challenges. These eight unique virtual races can be completed any time from anywhere in the world. Simply complete the required medal distance using a GPS recording, submit the evidence via email then sit back and wait for your impressive medal to arrive. Distances vary from three kilometres (1.8 miles) for a Mercury medal to a whopping 21 kilometres (13 miles) for Neptune.

FOR SOLAR OBSERVING

EXPLORE SCIENTIFIC SOLARIX A4 SOLAR FILTER FILM

Cost: £19.50 (approx. $27.10)

From: firstlightoptics.com

5 Don't let the longer days completely hinder your astronomical observations. Why not make your own solar filter and safely gaze at our impressive Sun? Suitable for use on telescopes, binoculars, cameras or even making a pair of eclipse glasses, this filter film creates a natural, yellow solar image. The filter is suitable for use at high magnifications and provides a consistent brightness and density with any aperture. A must-have accessory for anyone wanting to observe incredible solar sights such as sunspots and planet transits.

FOR TIMEKEEPING

SWATCH SPACE COLLECTION WATCHES

Cost: From £70 / $85

From: Swatch

6 The new Swatch Space Collection features six space-age watches with designs influenced by NASA and its iconic spacesuits. This particularly striking watch's design was influenced by the orange Advanced Crew Escape Suit, affectionately known as the pumpkin suit. This statement watch has the last ten seconds of the watch face timer highlighted in red as a nod to the final countdown to liftoff. The bioceramic watch is two-thirds ceramic and one-third biosourced plastic and is water resistant to 30 metres.

DR GEORGE CARRUTHERS

This physicist's inventions helped scientists see our planet – and the universe – in a whole new light

Carruthers holding a film cassette brought back from the Moon

© NASA

Carruthers' distinguished career gifted the scientific community with bold new instruments and many firsts. He is famed for his outstanding contributions to science and technology, inventing an ultraviolet observatory that would eventually take pride of place on the Moon.

His fascination with science began at an early age, having built his first telescope at the age of ten. He earned his PhD in aeronautical and astronautical engineering from the University of Illinois in 1964. He then went on to work at the US Naval Research Laboratory, where he was involved in projects spanning Apollo to the Space Shuttle era and beyond.

In 1969 Carruthers secured a patent for his 'Image Converter for Detecting Electromagnetic Radiation Especially in Short Wave Lengths' – an instrument that would soon revolutionise the way we viewed the cosmos. In 1970 this groundbreaking technology was launched into space on a sounding rocket, providing the first evidence of the existence of interstellar molecular hydrogen, a crucial building block for star formation.

In 1972, during Apollo 16, Carruthers' Moon-based observatory – the Far Ultraviolet Camera/Spectrograph – was used for the first time by astronaut John Young to photograph nebulae, galaxies and Earth's outermost atmosphere. It was called a camera/spectrograph due to the two modes of operation it could achieve. It could take direct images in a similar fashion to a regular camera, but it could also function as a spectrograph and split light into different wavelengths to identify 'fingerprints' of atoms and molecules in the sample.

This marked the first time astronomical observations were achieved from the surface of a planetary body other than Earth. Carruthers' instrument was carefully placed in the shadow of the Orion Lunar Module so as to shield the telescope from direct sunlight that would interfere with observations. The astronauts of Apollo 16 returned with a total of 178 frames of film from the telescope after a mission that lasted just under three days. At present, Carruthers' gold-plated observatory remains silently perched in the Moon's Descartes Highlands with only the Lunar Module Orion for company. The Moon-based observatory provided a giant leap in our understanding of not only our own world, but also of the many stars, galaxies and nebulae that surround us.

Carruthers' influence on science and discovery didn't stop there. In 1986 Comet Halley was imaged in ultraviolet (UV) using sounding rockets carrying his spectrograph. In 1991 his Far Ultraviolet Cameras were used on the STS-39 Space Shuttle mission to study Earth's atmosphere, as well as interstellar objects such as comets and stars. Carruthers was also involved in pioneering research in UV imaging of Earth's polar aurorae and upper atmosphere with the Advanced Research and Global Observation Satellite (ARGOS), a Department of Defense satellite launched in 1999.

Carruthers' influence reached far beyond that of his scientific endeavours, as he was a great advocate for education. In the 1980s he helped launch a program designed to give high school students the opportunity to carry out research at the US Naval Research Laboratory. The Science and Engineering Apprentice Program (SEAP) has benefited countless students over the years, and is still going strong today. Carruthers also took the time to teach science classes at Howard University in Washington DC.

His significant achievements did not go unrecognised: in 2003 Carruthers was inducted into the National Inventors Hall of Fame, and he was awarded the prestigious 2012 National Medal of Technology and Innovation, the US' highest honour for technology achievement.

All About Space

Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Editor-in-Chief **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Staff Writer **Daisy Dobrijevic**
Production Editor **Nikole Robinson**
Research Editor **Baljeet Panesar**
Senior Art Editor **Duncan Crook**
Photography **Olly Curtis**

Contributors
Stuart Atkinson, Quentin Changeat, Charles Q. Choi, David Crookes, Chelsea Gohd, Robin Hague, Brian Keating, Christopher Manser, Pawel Pietrukowicz, Brent Robertson, Jillian M. Scudder, Brandon Specktor, Colin Stuart, Giles Sparrow, Brandon Specktor, Mike Wall, Andrew Webb

Cover images
Alamy; Tobias Roetsch

Photography
Alamy; ESA; ESO; NASA; Science Photo Library; Shutterstock; SpaceX; University of Arizona; Wikipedia Commons;
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
Account Manager **Garry Brookes**
garry.brookes@futurenet.com
0330 390 6637
Advertising Director **Matt Johnston**
matthew.johnston@futurenet.com
07974 408083

International Licensing and Syndication
All About Space is available for licensing and syndication. To find our more contact us at **licensing@futurenet.com** or view our available content at **www.futurecontenthub.com**.
Head of Print Licensing **Rachel Shaw**
licensing@futurenet.com

Subscriptions
Enquiries **help@magazinesdirect.com**
UK orderline & enquiries **0330 333 1113**
Overseas order line & enquiries **+44 (0)330 333 1113**
Online orders & enquiries **www.magazinesdirect.com**
CRM Director **Louise Dudfield**

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Clare Scott**
Senior Advertising Production Manager **Jo Crosby**
Digital Editions Controller **Jason Hudson**
Production Manager **Nick Williams**

Management
Chief Content Officer **Angela O' Farrell**
Commercial Finance Director **Dan Jotcham**
Managing Director **Sarah Rafati Howard**
Head of Art & Design **Greg Whitaker**

Printed by William Gibbons & Sons Limited, 26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU www.marketforce.co.uk Tel: 0203 787 9060

ISSN 2050-0548

All contents © 2021 Future Publishing Limited or published under licence. All rights reserved. No part of this magazine may be used, stored, transmitted or reproduced in any way without the prior written permission of the publisher. Future Publishing Limited (company number 2008885) is registered in England and Wales. Registered office: Quay House, The Ambury, Bath BA1 1UA. All information contained in this publication is for information only and is, as far as we are aware, correct at the time of going to press. Future cannot accept any responsibility for errors or inaccuracies in such information. You are advised to contact manufacturers and retailers directly with regard to the price of products/services referred to in this publication. Apps and websites mentioned in this publication are not under our control. We are not responsible for their contents or any other changes or updates to them. This magazine is fully independent and not affiliated in any way with the companies mentioned herein.

If you submit material to us, you warrant that you own the material and/or have the necessary rights/permissions to supply the material and you automatically grant Future and its licensees a licence to publish your submission in whole or in part in any/all issues and/or editions of publications, in any format published worldwide and on associated websites, social media channels and associated products. Any material you submit is sent at your own risk and, although every care is taken, neither Future nor its employees, agents, subcontractors or licensees shall be liable for loss or damage. We assume all unsolicited material is for publication unless otherwise stated, and reserve the right to edit, amend, adapt all submissions.

Widely Recycled

We are committed to only using magazine paper which is derived from responsibly managed, certified forestry and chlorine-free manufacture. The paper in this magazine was sourced and produced from sustainable managed forests, conforming to strict environmental and socioeconomic standards. The manufacturing paper mill and paper hold full FSC and PEFC certification and accreditation.

FUTURE
Connectors. Creators. Experience Makers.

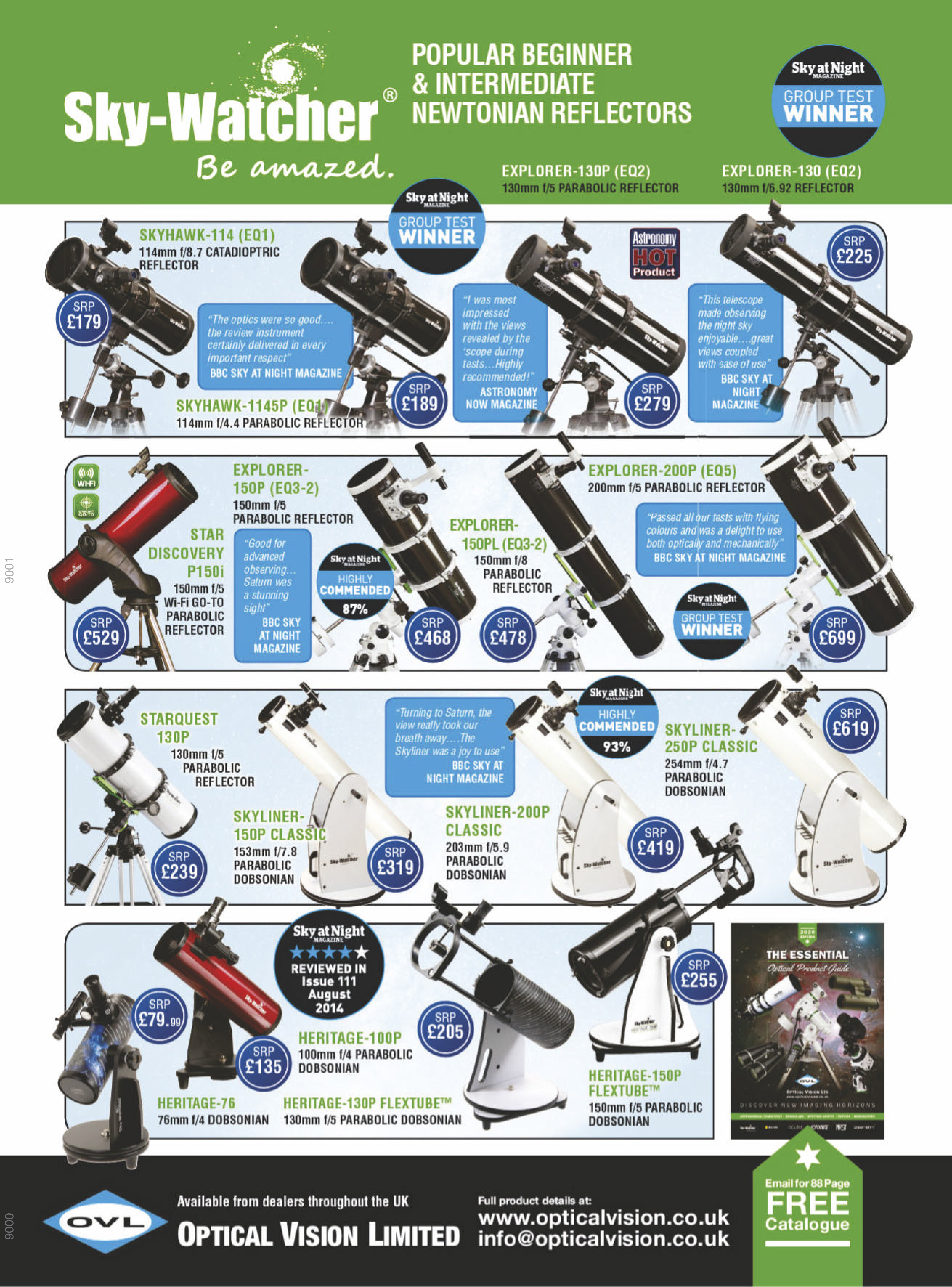
Future PLC is a public company quoted on the London Stock Exchange (symbol: FUTR)
www.futureplc.com

Chief Executive **Zillah Byng-Thorne**
Non-executive Chairman **Richard Huntingford**
Chief Financial Officer **Rachel Addison**

Tel +44 (0)1225 442 244

ipso. Regulated

WAR THUNDER
New? GET YOUR FREE BONUS
Experience the Battle of Britain yourself in War Thunder!
PLAY NOW FOR FREE
WARTHUNDER.COM/FLY
Gaijin
XBOX ONE
PS4
Windows
STEAM
Mac
oculus
VIVE
12
www.pegi.info



Sky-Watcher®
Be amazed.

POPULAR BEGINNER & INTERMEDIATE NEWTONIAN REFLECTORS

Sky at Night MAGAZINE GROUP TEST WINNER

SKYHAWK-114 (EQ1)
114mm f/8.7 CATADIOPTRIC REFLECTOR
SRP £179

SKYHAWK-1145P (EQ1)
114mm f/4.4 PARABOLIC REFLECTOR
SRP £189
Sky at Night MAGAZINE GROUP TEST WINNER
"The optics were so good.... the review instrument certainly delivered in every important respect"
BBC SKY AT NIGHT MAGAZINE

EXPLORER-130P (EQ2)
130mm f/5 PARABOLIC REFLECTOR
SRP £279
Astronomy NOW HOT Product
"I was most impressed with the views revealed by the 'scope during tests…Highly recommended!"
ASTRONOMY NOW MAGAZINE

EXPLORER-130 (EQ2)
130mm f/6.92 REFLECTOR
SRP £225
"This telescope made observing the night sky enjoyable….great views coupled with ease of use"
BBC SKY AT NIGHT MAGAZINE

STAR DISCOVERY P150i
150mm f/5 Wi-Fi GO-TO PARABOLIC REFLECTOR
Wi-Fi GO-TO
SRP £529

EXPLORER-150P (EQ3-2)
150mm f/5 PARABOLIC REFLECTOR
SRP £468
Sky at Night MAGAZINE HIGHLY COMMENDED 87%
"Good for advanced observing... Saturn was a stunning sight"
BBC SKY AT NIGHT MAGAZINE

EXPLORER-150PL (EQ3-2)
150mm f/8 PARABOLIC REFLECTOR
SRP £478

EXPLORER-200P (EQ5)
200mm f/5 PARABOLIC REFLECTOR
SRP £699
Sky at Night MAGAZINE GROUP TEST WINNER
"Passed all our tests with flying colours and was a delight to use both optically and mechanically"
BBC SKY AT NIGHT MAGAZINE

STARQUEST 130P
130mm f/5 PARABOLIC REFLECTOR
SRP £239

SKYLINER-150P CLASSIC
153mm f/7.8 PARABOLIC DOBSONIAN
SRP £319

SKYLINER-200P CLASSIC
203mm f/5.9 PARABOLIC DOBSONIAN
SRP £419
"Turning to Saturn, the view really took our breath away….The Skyliner was a joy to use"
BBC SKY AT NIGHT MAGAZINE

SKYLINER-250P CLASSIC
254mm f/4.7 PARABOLIC DOBSONIAN
SRP £619
Sky at Night MAGAZINE HIGHLY COMMENDED 93%

HERITAGE-76
76mm f/4 DOBSONIAN
SRP £79.99

HERITAGE-100P
100mm f/4 PARABOLIC DOBSONIAN
SRP £135
Sky at Night MAGAZINE ★★★★★ REVIEWED IN Issue 111 August 2014

HERITAGE-130P FLEXTUBE™
130mm f/5 PARABOLIC DOBSONIAN
SRP £205

HERITAGE-150P FLEXTUBE™
150mm f/5 PARABOLIC DOBSONIAN
SRP £255

Available from dealers throughout the UK
OVL **OPTICAL VISION LIMITED**

Full product details at:
www.opticalvision.co.uk
info@opticalvision.co.uk

Email for 88 Page FREE Catalogue